PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B41J 2/04, H04N 1/23	A1	(11) International Publication Number: WO 96/32265 (43) International Publication Date: 17 October 1996 (17.10.96)

(21) International Application Number: PCT/US96/04907

(22) International Filing Date: 10 April 1996 (10.04.96)

(30) Priority Data:

PN 2296	12 April 1995 (12.04.95)	AU
PN 2293	12 April 1995 (12.04.95)	AU

(71) Applicant (*for all designated States except US*): EASTMAN KODAK COMPANY [US/US]; 343 State Street, Rochester, NY 14650 (US).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): SILVERBROOK, Kia [AU/AU]; 214 Catherine Street, Leichhardt, NSW 2040 (AU).

(74) Agent: SALES, Milton, S.; 343 State Street, Rochester, NY 14650-2201 (US).

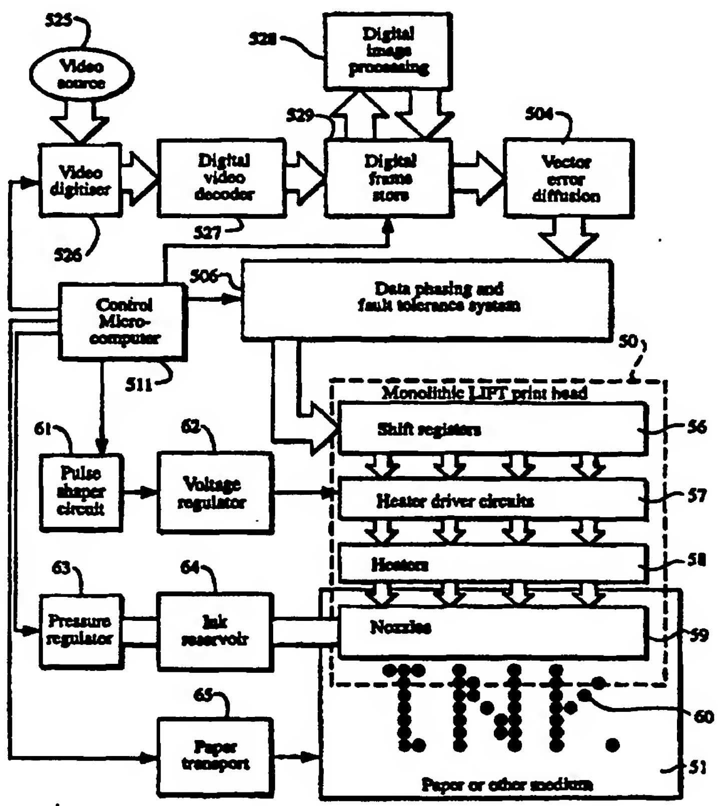
(81) Designated States: US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: A COLOR VIDEO PRINTER AND A PHOTOCD SYSTEM WITH INTEGRATED PRINTER

(57) Abstract

A color video printer and a photoCD player which use a Liquid Ink Fault Tolerant (LIFT) drop on demand printing mechanism. The color video printer system comprises a video format converter which changes the video input format to a form suitable for storage in a digital frame store, a digital frame store, an optional digital image processing system, a digital halftoning unit (preferably using vector error diffusion), a data phasing unit, and a concurrent drop selection and drop separation printing mechanism using liquid ink. The system operates by capturing a single frame of a video signal. This frame is stored in a continuous tone frame store. The image may be processed to remove inter-field motion artifacts, or to provide various forms of image enhancement. When the image is ready to be printed, the digital image contained in the frame store is digitally halftoned in real-time and printed by the printing head. The PhotoCD player operates in a usual manner when viewing digitally encoded photographs on a television set or video monitor. When a photograph is to be printed, the digitally compressed and encoded data is read from the PhotoCD using a CD-ROM drive. This data is decompressed into continuous tone raster image data, which is converted to a bi-level image by digital halftoning, and stored in a bi-level image memory. The contents f the bi-level image memory can then be printed using the concurrent drop selection and drop separation printing head.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgystan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic			SE	Sweden
CG	Congo	KR	Republic of Korea	SG	Singapore
CH	Switzerland	KZ	Kazakhstan	SI	Slovenia
CI	Côte d'Ivoire	LI	Liechtenstein	SK	Slovakia
CM	Cameroon	LK	Sri Lanka	SN	Senegal
CN	China	LR	Liberia	SZ	Swaziland
CS	Czechoslovakia	LT	Lithuania	TD	Chad
CZ	Czech Republic	LU	Luxembourg	TG	Togo
DE	Germany	LV	Latvia	TJ	Tajikistan
DK	Denmark	MC	Monaco	TT	Trinidad and Tobago
EE	Estonia	MD	Republic of Moldova	UA	Ukraine
ES	Spain	MG	Madagascar	UG	Uganda
FI	Finland	ML	Mali	US	United States of America
FR	France	MN	Mongolia	UZ	Uzbekistan
GA	Gabon	MR	Mauritania	VN	Viet Nam

A COLOR VIDEO PRINTER AND A PHOTO CD SYSTEM WITH INTEGRATED PRINTER

Field of the Invention

The present invention is in the field of computer controlled printing devices. In particular, the field is thermally activated drop on demand (DOD) printing systems.

The present invention is an apparatus for printing color images from a video signal. Color video printers can be used to obtain printed images, or 'hard copy', from various video sources. Examples of these sources are still video cameras, video cassette recorders, video camcorders, security cameras, video equipped computers, multi-media computers, broadcast television, cable television, and video-conferencing systems. Video printers have not yet become a high volume consumer item. One reason for slow acceptance of video printers is their high price relative to their perceived benefit. Another reason is that video images typically look poor when printed larger than a 40 mm diagonal. This is due to the low resolution of video images. Another reason is the high print cost for each image printed, as many video printers require special paper or Dye Diffusion Thermal Transfer (D2T2) sheets. Slow print times have also been a factor in the low market acceptance of video printers. The major obstacle in the development of low cost, high quality video printers has been the lack of a suitable color printing mechanism.

Eastman Kodak Company of the USA has developed an electronic photograph storage and viewing system called PhotoCD. This system uses writable CD-ROMs to store digital representations of photographic images. These images can be viewed using a television set, or can be transferred to a computer system and used for such purposes as desktop publishing. Eastman Kodak and other manufacturers are producing devices intended for the consumer market which allow the viewing of these digitally stored photographs on domestic television sets. These devices are called PhotoCD "players". These players allow the user to view photographs on a television set, but should the user require a print of one or more

of the images, the PhotoCD must be taken to a suitably equipped photograph processing lab. Many consumers are likely to require the ability to make a print quickly, and on demand. This feature can be achieved by either connecting or incorporating a digital color printer into the PhotoCD player. However, in the prior art, there exists no color printing technology which is sufficiently low in cost and high in quality to produce a satisfactory solution to this problem.

Background of the Invention

Many different types of digitally controlled printing systems have been invented, and many types are currently in production. These printing systems use a variety of actuation mechanisms, a variety of marking materials, and a variety of recording media. Examples of digital printing systems in current use include: laser electrophotographic printers; LED electrophotographic printers; dot matrix impact printers; thermal paper printers; film recorders; thermal wax printers; dye diffusion thermal transfer printers; and ink jet printers. However, at present, such electronic printing systems have not significantly replaced mechanical printing presses, even though this conventional method requires very expensive setup and is seldom commercially viable unless a few thousand copies of a particular page are to be printed. Thus, there is a need for improved digitally controlled printing systems, for example, being able to produce high quality color images at a high-speed and low cost, using standard paper.

Inkjet printing has become recognized as a prominent contender in the digitally controlled, electronic printing arena because, e.g., of its non-impact, low-noise characteristics, its use of plain paper and its avoidance of toner transfers and fixing.

Many types of ink jet printing mechanisms have been invented. These can be categorized as either continuous ink jet (CIJ) or drop on demand (DOD) ink jet. Continuous ink jet printing dates back to at least 1929: Hansell, US Pat. No. 1,941,001.

Sweet et al US Pat. No. 3,373,437, 1967, discloses an array of continuous ink jet nozzles where ink drops to be printed are selectively charged and

deflected towards the recording medium. This technique is known as binary deflection CIJ, and is used by several manufacturers, including Elmjet and Scitex.

Hertz et al US Pat. No. 3,416,153, 1966, discloses a method of achieving variable optical density of printed spots in CIJ printing using the electrostatic dispersion of a charged drop stream to modulate the number of droplets which pass through a small aperture. This technique is used in ink jet printers manufactured by Iris Graphics.

Kyser et al US Pat. No. 3,946,398, 1970, discloses a DOD ink jet printer which applies a high voltage to a piezoelectric crystal, causing the crystal to bend, applying pressure on an ink reservoir and jetting drops on demand. Many types of piezoelectric drop on demand printers have subsequently been invented, which utilize piezoelectric crystals in bend mode, push mode, shear mode, and squeeze mode. Piezoelectric DOD printers have achieved commercial success using hot melt inks (for example, Tektronix and Dataproducts printers), and at image resolutions up to 720 dpi for home and office printers (Seiko Epson). Piezoelectric DOD printers have an advantage in being able to use a wide range of inks. However, piezoelectric printing mechanisms usually require complex high voltage drive circuitry and bulky piezoelectric crystal arrays, which are disadvantageous in regard to manufacturability and performance.

Endo et al GB Pat. No. 2,007,162, 1979, discloses an electrothermal DOD ink jet printer which applies a power pulse to an electrothermal transducer (heater) which is in thermal contact with ink in a nozzle. The heater rapidly heats water based ink to a high temperature, whereupon a small quantity of ink rapidly evaporates, forming a bubble. The formation of these bubbles results in a pressure wave which cause drops of ink to be ejected from small apertures along the edge of the heater substrate. This technology is known as Bubblejet™ (trademark of Canon K.K. of Japan), and is used in a wide range of printing systems from Canon, Xerox, and other manufacturers.

Vaught et al US Pat. No. 4,490,728, 1982, discloses an electrothermal drop ejection system which also operates by bubble formation. In

this system, drops are ejected in a direction normal to the plane of the heater substrate, through nozzles formed in an aperture plate positioned above the heater. This system is known as Thermal Ink Jet, and is manufactured by Hewlett-Packard. In this document, the term Thermal Ink Jet is used to refer to both the Hewlett-Packard system and systems commonly known as Bubblejet™.

Thermal Ink Jet printing typically requires approximately 20 μJ over a period of approximately 2 μs to eject each drop. The 10 Watt active power consumption of each heater is disadvantageous in itself and also necessitates special inks, complicates the driver electronics and precipitates deterioration of heater elements.

Other ink jet printing systems have also been described in technical literature, but are not currently used on a commercial basis. For example, U.S. Patent No. 4,275,290 discloses a system wherein the coincident address of predetermined print head nozzles with heat pulses and hydrostatic pressure, allows ink to flow freely to spacer-separated paper, passing beneath the print head. U.S. Patent Nos. 4,737,803; 4,737,803 and 4,748,458 disclose ink jet recording systems wherein the coincident address of ink in print head nozzles with heat pulses and an electrostatically attractive field cause ejection of ink drops to a print sheet.

Each of the above-described inkjet printing systems has advantages and disadvantages. However, there remains a widely recognized need for an improved ink jet printing approach, providing advantages for example, as to cost, speed, quality, reliability, power usage, simplicity of construction and operation, durability and consumables.

Summary of the Invention

My concurrently filed applications, entitled "Liquid Ink Printing Apparatus and System" and "Coincident Drop-Selection, Drop-Separation Printing Method and System" describe new methods and apparatus that afford significant improvements toward overcoming the prior art problems discussed above. Those inventions offer important advantages, e.g., in regard to drop size and placement

accuracy, as to printing speeds attainable, as to power usage, as to durability and operative thermal stresses encountered and as to other printer performance characteristics, as well as in regard to manufacturability and the characteristics of useful inks. One important purpose of the present invention is to further enhance the structures and methods described in those applications and thereby contribute to the advancement of printing technology.

The invention provides a color video printer using a drop on demand printing head operating on the concurrent drop selection and drop separation printing principle.

A preferred form of the invention provides a color video printing apparatus comprising:

1) a video input format conversion process;
2) a digital frame store;
3) a digital halftoning unit which converts the continuous tone image data stored in the digital frame store to bi-level image data;
4) a data distribution and timing system which provides the bi-level image data to the printing head at the correct time during a printing operation; and
5) a bi-level color printing mechanism operating on the concurrent drop selection and drop separation printing principle.

A preferred aspect of the invention is that the bi-level printing mechanism is a single monolithic concurrent drop selection and drop separation printing head which can print to the full width of the photographic print.

A alternative preferred aspect of the invention is that the bi-level printing mechanism is composed of a plurality of monolithic concurrent drop selection and drop separation printing heads.

A preferred aspect of the invention is that the print paper is in the form of pre-cut sheets.

An alternative preferred aspect of the invention is that the print paper is in the form of a continuous roll, and which incorporates an automatic paper cutter.

Another preferred form of the invention is a color video printing apparatus comprising:

1) a video input format conversion process;
2) a digital frame store;
3) a digital image processing system;
4) a digital halftoning unit which converts the continuous tone image data stored in the digital frame store to bi-level image data;
5) a data distribution and timing system which provides the bi-level image data to the printing head at the correct time during a printing operation; and
6) a bi-level color printing mechanism operating on the concurrent drop selection and drop separation printing principle.

A preferred aspect of the invention is that the digital image processing unit removes inter-field motion artifacts from the digital image in the frame store.

Another preferred aspect of the invention is that the digital image processing unit reduces image noise in the digital image in the frame store.

Another preferred aspect of the invention is that the digital image processing unit digitally filters the digital image in the frame store.

Another preferred aspect of the invention is that the digital image processing unit comprises a microprocessor or microcomputer, interface hardware, and image processing software.

Another preferred form of the invention provides a PhotoCD player incorporating a printing apparatus comprising:

1) a computing element;
2) digital data storage system;
3) a CD-ROM drive;
4) an image decompression system;
5) a digital halftoning system;
6) a bi-level image memory;
7) a data distribution and timing system which provides the bi-level image data to the printing head at the correct time during a printing operation; and

8) a bi-level printing mechanism operating on the concurrent drop selection and drop separation printing principle.

Brief Description of the Drawings

Figure 1(a) shows a simplified block schematic diagram of one exemplary printing apparatus according to the present invention.

Figure 1(b) shows a cross section of one variety of nozzle tip in accordance with the invention.

Figures 2(a) to 2(f) show fluid dynamic simulations of drop selection.

Figure 3(a) shows a finite element fluid dynamic simulation of a nozzle in operation according to an embodiment of the invention.

Figure 3(b) shows successive meniscus positions during drop selection and separation.

Figure 3(c) shows the temperatures at various points during a drop selection cycle.

Figure 3(d) shows measured surface tension versus temperature curves for various ink additives.

Figure 3(e) shows the power pulses which are applied to the nozzle heater to generate the temperature curves of figure 3(c)

Figure 4 shows a block schematic diagram of print head drive circuitry for practice of the invention.

Figure 5 shows projected manufacturing yields for an A4 page width color print head embodying features of the invention, with and without fault tolerance.

Figure 6(a) shows a simplified schematic diagram of a color video printer using a concurrent drop selection and drop separation printing technology.

Figure 6(b) shows a simplified schematic diagram of a PhotoCD player incorporating a printer using concurrent drop selection and drop separation printing technology.

Figure 7(a) shows a top view of major component placement in one configuration of the printer.

Figure 7(b) shows a side view of major component placement in one configuration of the printer.

Figure 8 shows a perspective view of one possible configuration of the printer.

Detailed Description of Preferred Embodiments

According to one feature of the invention, a color video printer uses a drop on demand concurrent drop selection and drop separation printing mechanism. The system consists of a video digitizer, a digital video frame store, an optional digital image processing system, a digital halftoning unit, a data phasing unit, and a printing mechanism using liquid ink. The print is created in three stages. These are an image capture stage, where a single frame of a video signal is digitally captured in real-time and stored in a frame store. The second stage is an image processing stage, which may be implemented in software and is not required to occur in real time. The major functions of this stage are the removal of motion between the two fields of the video frame, image enhancement, and optional image effects. The third stage is printing the image. In this stage continuous tone image information from the frame store is digitally halftoned and printed by the printing head.

According to another feature of the invention, a user can view digitally encoded photographic images on a television set or video monitor. During viewing, a television resolution version of the image is read from the PhotoCD, stored in semiconductor memory, decompressed, and displayed on the television monitor. The user can 'browse' through these images at will. When the user wishes to print one of these images, a high resolution version of the image, also stored on the PhotoCD, is accessed.

This high resolution image is decompressed and converted to a bi-level image by vector error diffusion or an alternative form of digital halftoning, and

stored in a bi-level image memory. The contents of the bi-level image memory are then printed using a LIFT printing head.

In one general aspect, the invention constitutes a drop-on-demand printing mechanism wherein the means of selecting drops to be printed produces a difference in position between selected drops and drops which are not selected, but which is insufficient to cause the ink drops to overcome the ink surface tension and separate from the body of ink, and wherein an alternative means is provided to cause separation of the selected drops from the body of ink.

The separation of drop selection means from drop separation means significantly reduces the energy required to select which ink drops are to be printed. Only the drop selection means must be driven by individual signals to each nozzle. The drop separation means can be a field or condition applied simultaneously to all nozzles.

The drop selection means may be chosen from, but is not limited to, the following list:

1) Electrothermal reduction of surface tension of pressurized ink
2) Electrothermal bubble generation, with insufficient bubble volume to cause drop ejection
3) Piezoelectric, with insufficient volume change to cause drop ejection
4) Electrostatic attraction with one electrode per nozzle

The drop separation means may be chosen from, but is not limited to, the following list:

1) Proximity (recording medium in close proximity to print head)
2) Proximity with oscillating ink pressure
3) Electrostatic attraction
4) Magnetic attraction

The table "DOD printing technology targets" shows some desirable characteristics of drop on demand printing technology. The table also lists some methods by which some embodiments described herein, or in other of my related applications, provide improvements over the prior art.

DOD printing technology targets

Target	Method of achieving improvement over prior art
High speed operation	Practical, low cost, pagewidth printing heads with more than 10,000 nozzles. Monolithic A4 pagewidth print heads can be manufactured using standard 300 mm (12") silicon wafers
High image quality	High resolution (800 dpi is sufficient for most applications), six color process to reduce image noise
Full color operation	Halftoned process color at 800 dpi using stochastic screening
Ink flexibility	Low operating ink temperature and no requirement for bubble formation
Low power requirements	Low power operation results from drop selection means not being required to fully eject drop
Low cost	Monolithic print head without aperture plate, high manufacturing yield, small number of electrical connections, use of modified existing CMOS manufacturing facilities
High manufacturing yield	Integrated fault tolerance in printing head
High reliability	Integrated fault tolerance in printing head. Elimination of cavitation and kogation. Reduction of thermal shock.
Small number of electrical connections	Shift registers, control logic, and drive circuitry can be integrated on a monolithic print head using standard CMOS processes
Use of existing VLSI manufacturing facilities	CMOS compatibility. This can be achieved because the heater drive power is less is than 1% of Thermal Ink Jet heater drive power
Electronic collation	A new page compression system which can achieve 100:1 compression with insignificant image degradation, resulting in a compressed data rate low enough to allow real-time printing of any combination of thousands of pages stored on a low cost magnetic disk drive.

In thermal ink jet (TIJ) and piezoelectric ink jet systems, a drop velocity of approximately 10 meters per second is preferred to ensure that the selected ink drops overcome ink surface tension, separate from the body of the ink,

and strike the recording medium. These systems have a very low efficiency of conversion of electrical energy into drop kinetic energy. The efficiency of TIJ systems is approximately 0.02%). This means that the drive circuits for TIJ print heads must switch high currents. The drive circuits for piezoelectric ink jet heads must either switch high voltages, or drive highly capacitive loads. The total power consumption of pagewidth TIJ printheads is also very high. An 800 dpi A4 full color pagewidth TIJ print head printing a four color black image in one second would consume approximately 6 kW of electrical power, most of which is converted to waste heat. The difficulties of removal of this amount of heat precludes the production of low cost, high speed, high resolution compact pagewidth TIJ systems.

One important feature of embodiments of the invention is a means of significantly reducing the energy required to select which ink drops are to be printed. This is achieved by separating the means for selecting ink drops from the means for ensuring that selected drops separate from the body of ink and form dots on the recording medium. Only the drop selection means must be driven by individual signals to each nozzle. The drop separation means can be a field or condition applied simultaneously to all nozzles.

The table "Drop selection means" shows some of the possible means for selecting drops in accordance with the invention. The drop selection means is only required to create sufficient change in the position of selected drops that the drop separation means can discriminate between selected and unselected drops.

Drop selection means

Method	Advantage	Limitation
1. Electrothermal reduction of surface tension of pressurized ink	Low temperature increase and low drop selection energy. Can be used with many ink types. Simple fabrication. CMOS drive circuits can be fabricated on same substrate	Requires ink pressure regulating mechanism. Ink surface tension must reduce substantially as temperature increases

2. Electrothermal reduction of ink viscosity, combined with oscillating ink pressure	Medium drop selection energy, suitable for hot melt and oil based inks. Simple fabrication. CMOS drive circuits can be fabricated on same substrate	Requires ink pressure oscillation mechanism. Ink must have a large decrease in viscosity as temperature increases
3. Electrothermal bubble generation, with insufficient bubble volume to cause drop ejection	Well known technology, simple fabrication, bipolar drive circuits can be fabricated on same substrate	High drop selection energy, requires water based ink, problems with kogation, cavitation, thermal stress
4. Piezoelectric, with insufficient volume change to cause drop ejection	Many types of ink base can be used	High manufacturing cost, incompatible with integrated circuit processes, high drive voltage, mechanical complexity, bulky
5. Electrostatic attraction with one electrode per nozzle	Simple electrode fabrication	Nozzle pitch must be relatively large. Crosstalk between adjacent electric fields. Requires high voltage drive circuits

Other drop selection means may also be used.

The preferred drop selection means for water based inks is method 1: "Electrothermal reduction of surface tension of pressurized ink". This drop selection means provides many advantages over other systems, including; low power operation (approximately 1% of TIJ), compatibility with CMOS VLSI chip fabrication, low voltage operation (approx. 10 V), high nozzle density, low temperature operation, and wide range of suitable ink formulations. The ink must exhibit a reduction in surface tension with increasing temperature.

The preferred drop selection means for hot melt or oil based inks is method 2: "Electrothermal reduction of ink viscosity, combined with oscillating ink pressure". This drop selection means is particularly suited for use with inks which exhibit a large reduction of viscosity with increasing temperature, but only a small reduction in surface tension. This occurs particularly with non-polar ink carriers

with relatively high molecular weight. This is especially applicable to hot melt and oil based inks.

The table "Drop separation means" shows some of the possible methods for separating selected drops from the body of ink, and ensuring that the selected drops form dots on the printing medium. The drop separation means discriminates between selected drops and unselected drops to ensure that unselected drops do not form dots on the printing medium.

Drop separation means

Means	Advantage	Limitation
1. Electrostatic attraction	Can print on rough surfaces, simple implementation	Requires high voltage power supply
2. AC electric field	Higher field strength is possible than electrostatic, operating margins can be increased, ink pressure reduced, and dust accumulation is reduced	Requires high voltage AC power supply synchronized to drop ejection phase. Multiple drop phase operation is difficult
3. Proximity (print head in close proximity to, but not touching, recording medium)	Very small spot sizes can be achieved. Very low power dissipation. High drop position accuracy	Requires print medium to be very close to print head surface, not suitable for rough print media, usually requires transfer roller or belt
4. Transfer Proximity (print head is in close proximity to a transfer roller or belt	Very small spot sizes can be achieved, very low power dissipation, high accuracy, can print on rough paper	Not compact due to size of transfer roller or transfer belt.
5. Proximity with oscillating ink pressure	Useful for hot melt inks using viscosity reduction drop selection method, reduces possibility of nozzle clogging, can use pigments instead of dyes	Requires print medium to be very close to print head surface, not suitable for rough print media. Requires ink pressure oscillation apparatus

6. Magnetic attraction	Can print on rough surfaces. Low power if permanent magnets are used	Requires uniform high magnetic field strength, requires magnetic ink

Other drop separation means may also be used.

The preferred drop separation means depends upon the intended use. For most applications, method 1: "Electrostatic attraction", or method 2: "AC electric field" are most appropriate. For applications where smooth coated paper or film is used, and very high speed is not essential, method 3: "Proximity" may be appropriate. For high speed, high quality systems, method 4: "Transfer proximity" can be used. Method 6: "Magnetic attraction" is appropriate for portable printing systems where the print medium is too rough for proximity printing, and the high voltages required for electrostatic drop separation are undesirable. There is no clear 'best' drop separation means which is applicable to all circumstances.

Further details of various types of printing systems according to the present invention are described in the following Australian patent specifications filed on 12 April 1995, the disclosure of which are hereby incorporated by reference:

'A Liquid ink Fault Tolerant (LIFT) printing mechanism' (Filing no.: PN2308);

'Electrothermal drop selection in LIFT printing' (Filing no.: PN2309);

'Drop separation in LIFT printing by print media proximity' (Filing no.: PN2310);

'Drop size adjustment in Proximity LIFT printing by varying head to media distance' (Filing no.: PN2311);

'Augmenting Proximity LIFT printing with acoustic ink waves' (Filing no.: PN2312);

'Electrostatic drop separation in LIFT printing' (Filing no.: PN2313);

'Multiple simultaneous drop sizes in Proximity LIFT printing' (Filing no.: PN2321);

'Self cooling operation in thermally activated print heads' (Filing no.: PN2322); and

'Thermal Viscosity Reduction LIFT printing' (Filing no.: PN2323).

A simplified schematic diagram of one preferred printing system according to the invention appears in Figure 1(a).

An image source 52 may be raster image data from a scanner or computer, or outline image data in the form of a page description language (PDL), or other forms of digital image representation. This image data is converted to a pixel-mapped page image by the image processing system 53. This may be a raster image processor (RIP) in the case of PDL image data, or may be pixel image manipulation in the case of raster image data. Continuous tone data produced by the image processing unit 53 is halftoned. Halftoning is performed by the Digital Halftoning unit 54. Halftoned bitmap image data is stored in the image memory 72. Depending upon the printer and system configuration, the image memory 72 may be a full page memory, or a band memory. Heater control circuits 71 read data from the image memory 72 and apply time-varying electrical pulses to the nozzle heaters (103 in figure 1(b)) that are part of the print head 50. These pulses are applied at an appropriate time, and to the appropriate nozzle, so that selected drops will form spots on the recording medium 51 in the appropriate position designated by the data in the image memory 72.

The recording medium 51 is moved relative to the head 50 by a paper transport system 65, which is electronically controlled by a paper transport control system 66, which in turn is controlled by a microcontroller 315. The paper transport system shown in figure 1(a) is schematic only, and many different mechanical configurations are possible. In the case of pagewidth print heads, it is most convenient to move the recording medium 51 past a stationary head 50. However, in the case of scanning print systems, it is usually most convenient to move the head 50 along one axis (the sub-scanning direction) and the recording medium 51 along the orthogonal axis (the main scanning direction), in a relative raster motion. The microcontroller 315 may also control the ink pressure regulator 63 and the heater control circuits 71.

For printing using surface tension reduction, ink is contained in an ink reservoir 64 under pressure. In the quiescent state (with no ink drop ejected),

the ink pressure is insufficient to overcome the ink surface tension and eject a drop. A constant ink pressure can be achieved by applying pressure to the ink reservoir 64 under the control of an ink pressure regulator 63. Alternatively, for larger printing systems, the ink pressure can be very accurately generated and controlled by situating the top surface of the ink in the reservoir 64 an appropriate distance above the head 50. This ink level can be regulated by a simple float valve (not shown).

For printing using viscosity reduction, ink is contained in an ink reservoir 64 under pressure, and the ink pressure is caused to oscillate. The means of producing this oscillation may be a piezoelectric actuator mounted in the ink channels (not shown).

When properly arranged with the drop separation means, selected drops proceed to form spots on the recording medium 51, while unselected drops remain part of the body of ink.

The ink is distributed to the back surface of the head 50 by an ink channel device 75. The ink preferably flows through slots and/or holes etched through the silicon substrate of the head 50 to the front surface, where the nozzles and actuators are situated. In the case of thermal selection, the nozzle actuators are electrothermal heaters.

In some types of printers according to the invention, an external field 74 is required to ensure that the selected drop separates from the body of the ink and moves towards the recording medium 51. A convenient external field 74 is a constant electric field, as the ink is easily made to be electrically conductive. In this case, the paper guide or platen 67 can be made of electrically conductive material and used as one electrode generating the electric field. The other electrode can be the head 50 itself. Another embodiment uses proximity of the print medium as a means of discriminating between selected drops and unselected drops.

For small drop sizes gravitational force on the ink drop is very small; approximately 10^{-4} of the surface tension forces, so gravity can be ignored in most cases. This allows the print head 50 and recording medium 51 to be oriented in any

direction in relation to the local gravitational field. This is an important requirement for portable printers.

Figure 1(b) is a detail enlargement of a cross section of a single microscopic nozzle tip embodiment of the invention, fabricated using a modified CMOS process. The nozzle is etched in a substrate 101, which may be silicon, glass, metal, or any other suitable material. If substrates which are not semiconductor materials are used, a semiconducting material (such as amorphous silicon) may be deposited on the substrate, and integrated drive transistors and data distribution circuitry may be formed in the surface semiconducting layer. Single crystal silicon (SCS) substrates have several advantages, including:

1) High performance drive transistors and other circuitry can be fabricated in SCS;
2) Print heads can be fabricated in existing facilities (fabs) using standard VLSI processing equipment;
3) SCS has high mechanical strength and rigidity; and
4) SCS has a high thermal conductivity.

In this example, the nozzle is of cylindrical form, with the heater 103 forming an annulus. The nozzle tip 104 is formed from silicon dioxide layers 102 deposited during the fabrication of the CMOS drive circuitry. The nozzle tip is passivated with silicon nitride. The protruding nozzle tip controls the contact point of the pressurized ink 100 on the print head surface. The print head surface is also hydrophobized to prevent accidental spread of ink across the front of the print head.

Many other configurations of nozzles are possible, and nozzle embodiments of the invention may vary in shape, dimensions, and materials used. Monolithic nozzles etched from the substrate upon which the heater and drive electronics are formed have the advantage of not requiring an orifice plate. The elimination of the orifice plate has significant cost savings in manufacture and assembly. Recent methods for eliminating orifice plates include the use of 'vortex' actuators such as those described in Domoto et al US Pat. No. 4,580,158, 1986, assigned to Xerox, and Miller et al US Pat. No. 5,371,527, 1994 assigned to Hewlett-Packard. These, however are complex to actuate, and difficult to fabricate.

The preferred method for elimination of orifice plates for print heads of the invention is incorporation of the orifice into the actuator substrate.

This type of nozzle may be used for print heads using various techniques for drop separation.

Operation with Electrostatic Drop Separation

As a first example, operation using thermal reduction of surface tension and electrostatic drop separation is shown in figure 2.

Figure 2 shows the results of energy transport and fluid dynamic simulations performed using FIDAP, a commercial fluid dynamic simulation software package available from Fluid Dynamics Inc., of Illinois, USA. This simulation is of a thermal drop selection nozzle embodiment with a diameter of 8 μm, at an ambient temperature of 30°C. The total energy applied to the heater is 276 nJ, applied as 69 pulses of 4 nJ each. The ink pressure is 10 kPa above ambient air pressure, and the ink viscosity at 30°C is 1.84 cPs. The ink is water based, and includes a sol of 0.1% palmitic acid to achieve an enhanced decrease in surface tension with increasing temperature. A cross section of the nozzle tip from the central axis of the nozzle to a radial distance of 40 μm is shown. Heat flow in the various materials of the nozzle, including silicon, silicon nitride, amorphous silicon dioxide, crystalline silicon dioxide, and water based ink are simulated using the respective densities, heat capacities, and thermal conductivities of the materials. The time step of the simulation is 0.1 μs.

Figure 2(a) shows a quiescent state, just before the heater is actuated. An equilibrium is created whereby no ink escapes the nozzle in the quiescent state by ensuring that the ink pressure plus external electrostatic field is insufficient to overcome the surface tension of the ink at the ambient temperature. In the quiescent state, the meniscus of the ink does not protrude significantly from the print head surface, so the electrostatic field is not significantly concentrated at the meniscus.

Figure 2(b) shows thermal contours at 5°C intervals 5 μs after the start of the heater energizing pulse. When the heater is energized, the ink in contact with the nozzle tip is rapidly heated. The reduction in surface tension causes the heated portion of the meniscus to rapidly expand relative to the cool ink meniscus. This drives a convective flow which rapidly transports this heat over part of the free surface of the ink at the nozzle tip. It is necessary for the heat to be distributed over the ink surface, and not just where the ink is in contact with the heater. This is because viscous drag against the solid heater prevents the ink directly in contact with the heater from moving.

Figure 2(c) shows thermal contours at 5°C intervals 10 μs after the start of the heater energizing pulse. The increase in temperature causes a decrease in surface tension, disturbing the equilibrium of forces. As the entire meniscus has been heated, the ink begins to flow.

Figure 2(d) shows thermal contours at 5°C intervals 20 μs after the start of the heater energizing pulse. The ink pressure has caused the ink to flow to a new meniscus position, which protrudes from the print head. The electrostatic field becomes concentrated by the protruding conductive ink drop.

Figure 2(e) shows thermal contours at 5°C intervals 30 μs after the start of the heater energizing pulse, which is also 6 μs after the end of the heater pulse, as the heater pulse duration is 24 μs. The nozzle tip has rapidly cooled due to conduction through the oxide layers, and conduction into the flowing ink. The nozzle tip is effectively 'water cooled' by the ink. Electrostatic attraction causes the ink drop to begin to accelerate towards the recording medium. Were the heater pulse significantly shorter (less than 16 μs in this case) the ink would not accelerate towards the print medium, but would instead return to the nozzle.

Figure 2(f) shows thermal contours at 5°C intervals 26 μs after the end of the heater pulse. The temperature at the nozzle tip is now less than 5°C above ambient temperature. This causes an increase in surface tension around the nozzle tip. When the rate at which the ink is drawn from the nozzle exceeds the viscously limited rate of ink flow through the nozzle, the ink in the region of the

nozzle tip 'necks', and the selected drop separates from the body of ink. The selected drop then travels to the recording medium under the influence of the external electrostatic field. The meniscus of the ink at the nozzle tip then returns to its quiescent position, ready for the next heat pulse to select the next ink drop. One ink drop is selected, separated and forms a spot on the recording medium for each heat pulse. As the heat pulses are electrically controlled, drop on demand ink jet operation can be achieved.

Figure 3(a) shows successive meniscus positions during the drop selection cycle at 5 μs intervals, starting at the beginning of the heater energizing pulse.

Figure 3(b) is a graph of meniscus position versus time, showing the movement of the point at the centre of the meniscus. The heater pulse starts 10 μs into the simulation.

Figure 3(c) shows the resultant curve of temperature with respect to time at various points in the nozzle. The vertical axis of the graph is temperature, in units of 100°C. The horizontal axis of the graph is time, in units of 10 μs. The temperature curve shown in figure 3(b) was calculated by FIDAP, using 0.1 μs time steps. The local ambient temperature is 30 degrees C. Temperature histories at three points are shown:

A - Nozzle tip: This shows the temperature history at the circle of contact between the passivation layer, the ink, and air.

B - Meniscus midpoint: This is at a circle on the ink meniscus midway between the nozzle tip and the centre of the meniscus.

C - Chip surface: This is at a point on the print head surface 20 μm from the centre of the nozzle. The temperature only rises a few degrees. This indicates that active circuitry can be located very close to the nozzles without experiencing performance or lifetime degradation due to elevated temperatures.

Figure 3(e) shows the power applied to the heater. Optimum operation requires a sharp rise in temperature at the start of the heater pulse, a maintenance of the temperature a little below the boiling point of the ink for the

duration of the pulse, and a rapid fall in temperature at the end of the pulse. To achieve this, the average energy applied to the heater is varied over the duration of the pulse. In this case, the variation is achieved by pulse frequency modulation of 0.1 μs sub-pulses, each with an energy of 4 nJ. The peak power applied to the heater is 40 mW, and the average power over the duration of the heater pulse is 11.5 mW. The sub-pulse frequency in this case is 5 Mhz. This can readily be varied without significantly affecting the operation of the print head. A higher sub-pulse frequency allows finer control over the power applied to the heater. A sub-pulse frequency of 13.5 Mhz is suitable, as this frequency is also suitable for minimizing the effect of radio frequency interference (RFI).

Inks with a negative temperature coefficient of surface tension

The requirement for the surface tension of the ink to decrease with increasing temperature is not a major restriction, as most pure liquids and many mixtures have this property. Exact equations relating surface tension to temperature for arbitrary liquids are not available. However, the following empirical equation derived by Ramsay and Shields is satisfactory for many liquids:

$$\gamma_T = k\frac{(T_c - T - 6)}{\sqrt[3]{\left(\frac{Mx}{\rho}\right)^2}}$$

Where γ_T is the surface tension at temperature T, k is a constant, T_c is the critical temperature of the liquid, M is the molar mass of the liquid, x is the degree of association of the liquid, and ρ is the density of the liquid. This equation indicates that the surface tension of most liquids falls to zero as the temperature reaches the critical temperature of the liquid. For most liquids, the critical temperature is substantially above the boiling point at atmospheric pressure, so to achieve an ink with a large change in surface tension with a small change in temperature around a practical ejection temperature, the admixture of surfactants is recommended.

The choice of surfactant is important. For example, water based ink for thermal ink jet printers often contains isopropyl alcohol (2-propanol) to reduce the surface tension and promote rapid drying. Isopropyl alcohol has a boiling point of 82.4°C, lower than that of water. As the temperature rises, the alcohol evaporates faster than the water, decreasing the alcohol concentration and causing an increase in surface tension. A surfactant such as 1-Hexanol (b.p. 158°C) can be used to reverse this effect, and achieve a surface tension which decreases slightly with temperature. However, a relatively large decrease in surface tension with temperature is desirable to maximize operating latitude. A surface tension decrease of 20 mN/m over a 30°C temperature range is preferred to achieve large operating margins, while as little as 10mN/m can be used to achieve operation of the print head according to the present invention.

Inks With Large $-\Delta\gamma_T$

Several methods may be used to achieve a large negative change in surface tension with increasing temperature. Two such methods are:

1) The ink may contain a low concentration sol of a surfactant which is solid at ambient temperatures, but melts at a threshold temperature. Particle sizes less than 1,000 Å are desirable. Suitable surfactant melting points for a water based ink are between 50°C and 90°C, and preferably between 60°C and 80°C.
2) The ink may contain an oil/water microemulsion with a phase inversion temperature (PIT) which is above the maximum ambient temperature, but below the boiling point of the ink. For stability, the PIT of the microemulsion is preferably 20°C or more above the maximum non-operating temperature encountered by the ink. A PIT of approximately 80°C is suitable.

Inks with Surfactant Sols

Inks can be prepared as a sol of small particles of a surfactant which melts in the desired operating temperature range. Examples of such surfactants include carboxylic acids with between 14 and 30 carbon atoms, such as:

Name	Formula	m.p.	Synonym
Tetradecanoic acid	$CH_3(CH_2)_{12}COOH$	58°C	Myristic acid
Hexadecanoic acid	$CH_3(CH_2)_{14}COOH$	63°C	Palmitic acid
Octadecanoic acid	$CH_3(CH_2)_{15}COOH$	71°C	Stearic acid
Eicosanoic acid	$CH_3(CH_2)_{16}COOH$	77°C	Arachidic acid
Docosanoic acid	$CH_3(CH_2)_{20}COOH$	80°C	Behenic acid

As the melting point of sols with a small particle size is usually slightly less than of the bulk material, it is preferable to choose a carboxylic acid with a melting point slightly above the desired drop selection temperature. A good example is Arachidic acid.

These carboxylic acids are available in high purity and at low cost. The amount of surfactant required is very small, so the cost of adding them to the ink is insignificant. A mixture of carboxylic acids with slightly varying chain lengths can be used to spread the melting points over a range of temperatures. Such mixtures will typically cost less than the pure acid.

It is not necessary to restrict the choice of surfactant to simple unbranched carboxylic acids. Surfactants with branched chains or phenyl groups, or other hydrophobic moieties can be used. It is also not necessary to use a carboxylic acid. Many highly polar moieties are suitable for the hydrophilic end of the surfactant. It is desirable that the polar end be ionizable in water, so that the surface of the surfactant particles can be charged to aid dispersion and prevent flocculation. In the case of carboxylic acids, this can be achieved by adding an alkali such as sodium hydroxide or potassium hydroxide.

Preparation of Inks with Surfactant Sols

The surfactant sol can be prepared separately at high concentration, and added to the ink in the required concentration.

An example process for creating the surfactant sol is as follows:

1) Add the carboxylic acid to purified water in an oxygen free atmosphere.

2) Heat the mixture to above the melting point of the carboxylic acid. The water can be brought to a boil.
3) Ultrasonicate the mixture, until the typical size of the carboxylic acid droplets is between 100Å and 1,000Å.
4) Allow the mixture to cool.
5) Decant the larger particles from the top of the mixture.
6) Add an alkali such as NaOH to ionize the carboxylic acid molecules on the surface of the particles. A pH of approximately 8 is suitable. This step is not absolutely necessary, but helps stabilize the sol.
7) Centrifuge the sol. As the density of the carboxylic acid is lower than water, smaller particles will accumulate at the outside of the centrifuge, and larger particles in the centre.
8) Filter the sol using a microporous filter to eliminate any particles above 5000 Å.
9) Add the surfactant sol to the ink preparation. The sol is required only in very dilute concentration.

The ink preparation will also contain either dye(s) or pigment(s), bactericidal agents, agents to enhance the electrical conductivity of the ink if electrostatic drop separation is used, humectants, and other agents as required.

Anti-foaming agents will generally not be required, as there is no bubble formation during the drop ejection process.

Cationic surfactant sols

Inks made with anionic surfactant sols are generally unsuitable for use with cationic dyes or pigments. This is because the cationic dye or pigment may precipitate or flocculate with the anionic surfactant. To allow the use of cationic dyes and pigments, a cationic surfactant sol is required. The family of alkylamines is suitable for this purpose.

Various suitable alkylamines are shown in the following table:

Name	Formula	Synonym
Hexadecylamine	$CH_3(CH_2)_{14}CH_2NH_2$	Palmityl amine
Octadecylamine	$CH_3(CH_2)_{16}CH_2NH_2$	Stearyl amine
Eicosylamine	$CH_3(CH_2)_{18}CH_2NH_2$	Arachidyl amine
Docosylamine	$CH_3(CH_2)_{20}CH_2NH_2$	Behenyl amine

The method of preparation of cationic surfactant sols is essentially similar to that of anionic surfactant sols, except that an acid instead of an alkali is used to adjust the pH balance and increase the charge on the surfactant particles. A pH of 6 using HCl is suitable.

Microemulsion Based Inks

An alternative means of achieving a large reduction in surface tension as some temperature threshold is to base the ink on a microemulsion. A microemulsion is chosen with a phase inversion temperature (PIT) around the desired ejection threshold temperature. Below the PIT, the microemulsion is oil in water (O/W), and above the PIT the microemulsion is water in oil (W/O). At low temperatures, the surfactant forming the microemulsion prefers a high curvature surface around oil, and at temperatures significantly above the PIT, the surfactant prefers a high curvature surface around water. At temperatures close to the PIT, the microemulsion forms a continuous 'sponge' of topologically connected water and oil.

There are two mechanisms whereby this reduces the surface tension. Around the PIT, the surfactant prefers surfaces with very low curvature. As a result, surfactant molecules migrate to the ink/air interface, which has a curvature which is much less than the curvature of the oil emulsion. This lowers the surface tension of the water. Above the phase inversion temperature, the microemulsion changes from O/W to W/O, and therefore the ink/air interface changes from water/air to oil/air. The oil/air interface has a lower surface tension.

There is a wide range of possibilities for the preparation of microemulsion based inks.

For fast drop ejection, it is preferable to chose a low viscosity oil.

In many instances, water is a suitable polar solvent. However, in some cases different polar solvents may be required. In these cases, polar solvents with a high surface tension should be chosen, so that a large decrease in surface tension is achievable.

The surfactant can be chosen to result in a phase inversion temperature in the desired range. For example, surfactants of the group poly(oxyethylene)alkylphenyl ether (ethoxylated alkyl phenols, general formula: $C_nH_{2n+1}C_4H_6(CH_2CH_2O)_mOH$) can be used. The hydrophilicity of the surfactant can be increased by increasing m, and the hydrophobicity can be increased by increasing n. Values of m of approximately 10, and n of approximately 8 are suitable.

Low cost commercial preparations are the result of a polymerization of various molar ratios of ethylene oxide and alkyl phenols, and the exact number of oxyethylene groups varies around the chosen mean. These commercial preparations are adequate, and highly pure surfactants with a specific number of oxyethylene groups are not required.

The formula for this surfactant is $C_8H_{17}C_4H_6(CH_2CH_2O)_nOH$ (average n=10).

Synonyms include Octoxynol-10, PEG-10 octyl phenyl ether and POE (10) octyl phenyl ether

The HLB is 13.6, the melting point is 7°C, and the cloud point is 65°C.

Commercial preparations of this surfactant are available under various brand names. Suppliers and brand names are listed in the following table:

Trade name	Supplier
Akyporox OP100	Chem-Y GmbH
Alkasurf OP-10	Rhone-Poulenc Surfactants and Specialties
Dehydrophen POP 10	Pulcra SA
Hyonic OP-10	Henkel Corp.
Iconol OP-10	BASF Corp.
Igepal O	Rhone-Poulenc France
Macol OP-10	PPG Industries
Malorphen 810	Huls AG
Nikkol OP-10	Nikko Chem. Co. Ltd.
Renex 750	ICI Americas Inc.
Rexol 45/10	Hart Chemical Ltd.
Synperonic OP10	ICI PLC
Teric X10	ICI Australia

These are available in large volumes at low cost (less than one dollar per pound in quantity), and so contribute less than 10 cents per liter to prepared microemulsion ink with a 5% surfactant concentration.

Other suitable ethoxylated alkyl phenols include those listed in the following table:

Trivial name	Formula	HLB	Cloud point
Nonoxynol-9	$C_9H_{19}C_4H_6(CH_2CH_2O)_{-9}OH$	13	54°C
Nonoxynol-10	$C_9H_{19}C_4H_6(CH_2CH_2O)_{-10}OH$	13.2	62°C
Nonoxynol-11	$C_9H_{19}C_4H_6(CH_2CH_2O)_{-11}OH$	13.8	72°C
Nonoxynol-12	$C_9H_{19}C_4H_6(CH_2CH_2O)_{-12}OH$	14.5	81°C
Octoxynol-9	$C_8H_{17}C_4H_6(CH_2CH_2O)_{-9}OH$	12.1	61°C
Octoxynol-10	$C_8H_{17}C_4H_6(CH_2CH_2O)_{-10}OH$	13.6	65°C
Octoxynol-12	$C_8H_{17}C_4H_6(CH_2CH_2O)_{-12}OH$	14.6	88°C
Dodoxynol-10	$C_{12}H_{25}C_4H_6(CH_2CH_2O)_{-10}OH$	12.6	42°C

Dodoxynol-11	$C_{12}H_{25}C_4H_6(CH_2CH_2O)_{-11}OH$	13.5	56°C
Dodoxynol-14	$C_{12}H_{25}C_4H_6(CH_2CH_2O)_{-14}OH$	14.5	87°C

Microemulsion based inks have advantages other than surface tension control:

1) Microemulsions are thermodynamically stable, and will not separate. Therefore, the storage time can be very long. This is especially significant for office and portable printers, which may be used sporadically.
2) The microemulsion will form spontaneously with a particular drop size, and does not require extensive stirring, centrifuging, or filtering to ensure a particular range of emulsified oil drop sizes.
3) The amount of oil contained in the ink can be quite high, so dyes which are soluble in oil or soluble in water, or both, can be used. It is also possible to use a mixture of dyes, one soluble in water, and the other soluble in oil, to obtain specific colors.
4) Oil miscible pigments are prevented from flocculating, as they are trapped in the oil microdroplets.
5) The use of a microemulsion can reduce the mixing of different dye colors on the surface of the print medium.
6) The viscosity of microemulsions is very low.
7) The requirement for humectants can be reduced or eliminated.

Dyes and pigments in microemulsion based inks

Oil in water mixtures can have high oil contents - as high as 40% - and still form O/W microemulsions. This allows a high dye or pigment loading.

Mixtures of dyes and pigments can be used. An example of a microemulsion based ink mixture with both dye and pigment is as follows:

1) 70% water
2) 5% water soluble dye
3) 5% surfactant

4) 10% oil
5) 10% oil miscible pigment

The following table shows the nine basic combinations of colorants in the oil and water phases of the microemulsion that may be used.

Combination	Colorant in water phase	Colorant in oil phase
1	none	oil miscible pigment
2	none	oil soluble dye
3	water soluble dye	none
4	water soluble dye	oil miscible pigment
5	water soluble dye	oil soluble dye
6	pigment dispersed in water	none
7	pigment dispersed in water	oil miscible pigment
8	pigment dispersed in water	oil soluble dye
9	none	none

The ninth combination, with no colorants, is useful for printing transparent coatings, UV ink, and selective gloss highlights.

As many dyes are amphiphilic, large quantities of dyes can also be solubilized in the oil-water boundary layer as this layer has a very large surface area.

It is also possible to have multiple dyes or pigments in each phase, and to have a mixture of dyes and pigments in each phase.

When using multiple dyes or pigments the absorption spectrum of the resultant ink will be the weighted average of the absorption spectra of the different colorants used. This presents two problems:

1) The absorption spectrum will tend to become broader, as the absorption peaks of both colorants are averaged. This has a tendency to 'muddy' the colors. To obtain brilliant color, careful choice of dyes and pigments based on their absorption spectra, not just their human-perceptible color, needs to be made.
2) The color of the ink may be different on different substrates. If a dye and a pigment are used in combination, the color of the dye will tend to have a

smaller contribution to the printed ink color on more absorptive papers, as the dye will be absorbed into the paper, while the pigment will tend to 'sit on top' of the paper. This may be used as an advantage in some circumstances.

Surfactants with a Krafft point in the drop selection temperature range

For ionic surfactants there is a temperature (the Krafft point) below which the solubility is quite low, and the solution contains essentially no micelles. Above the Krafft temperature micelle formation becomes possible and there is a rapid increase in solubility of the surfactant. If the critical micelle concentration (CMC) exceeds the solubility of a surfactant at a particular temperature, then the minimum surface tension will be achieved at the point of maximum solubility, rather than at the CMC. Surfactants are usually much less effective below the Krafft point.

This factor can be used to achieve an increased reduction in surface tension with increasing temperature. At ambient temperatures, only a portion of the surfactant is in solution. When the nozzle heater is turned on, the temperature rises, and more of the surfactant goes into solution, decreasing the surface tension.

A surfactant should be chosen with a Krafft point which is near the top of the range of temperatures to which the ink is raised. This gives a maximum margin between the concentration of surfactant in solution at ambient temperatures, and the concentration of surfactant in solution at the drop selection temperature.

The concentration of surfactant should be approximately equal to the CMC at the Krafft point. In this manner, the surface tension is reduced to the maximum amount at elevated temperatures, and is reduced to a minimum amount at ambient temperatures.

The following table shows some commercially available surfactants with Krafft points in the desired range.

Formula	Krafft point
$C_{16}H_{33}SO_3^-Na^+$	57°C
$C_{18}H_{37}SO_3^-Na^+$	70°C
$C_{16}H_{33}SO_4^-Na^+$	45°C
$Na^{+-}O_4S(CH_2)_{16}SO_4^-Na^+$	44.9°C
$K^{+-}O_4S(CH_2)_{16}SO_4^-K^+$	55°C
$C_{16}H_{33}CH(CH_3)C_4H_6SO_3^-Na^+$	60.8°C

Surfactants with a cloud point in the drop selection temperature range

Non-ionic surfactants using polyoxyethylene (POE) chains can be used to create an ink where the surface tension falls with increasing temperature. At low temperatures, the POE chain is hydrophilic, and maintains the surfactant in solution. As the temperature increases, the structured water around the POE section of the molecule is disrupted, and the POE section becomes hydrophobic. The surfactant is increasingly rejected by the water at higher temperatures, resulting in increasing concentration of surfactant at the air/ink interface, thereby lowering surface tension. The temperature at which the POE section of a nonionic surfactant becomes hydrophilic is related to the cloud point of that surfactant. POE chains by themselves are not particularly suitable, as the cloud point is generally above 100°C

Polyoxypropylene (POP) can be combined with POE in POE/POP block copolymers to lower the cloud point of POE chains without introducing a strong hydrophobicity at low temperatures.

Two main configurations of symmetrical POE/POP block copolymers are available. These are:

1) Surfactants with POE segments at the ends of the molecules, and a POP segment in the centre, such as the poloxamer class of surfactants (generically CAS 9003-11-6)
2) Surfactants with POP segments at the ends of the molecules, and a POE segment in the centre, such as the meroxapol class of surfactants (generically also CAS 9003-11-6)

Some commercially available varieties of poloxamer and meroxapol with a high surface tension at room temperature, combined with a cloud point above 40°C and below 100°C are shown in the following table:

Trivial name	BASF Trade name	Formula	Surface Tension (mN/m)	Cloud point
Meroxapol 105	Pluronic 10R5	$HO(CHCH_3CH_2O)_{\sim 7}$-$(CH_2CH_2O)_{\sim 22}$-$(CHCH_3CH_2O)_{\sim 7}OH$	50.9	69°C
Meroxapol 108	Pluronic 10R8	$HO(CHCH_3CH_2O)_{\sim 7}$-$(CH_2CH_2O)_{\sim 91}$-$(CHCH_3CH_2O)_{\sim 7}OH$	54.1	99°C
Meroxapol 178	Pluronic 17R8	$HO(CHCH_3CH_2O)_{\sim 12}$-$(CH_2CH_2O)_{\sim 136}$-$(CHCH_3CH_2O)_{\sim 12}OH$	47.3	81°C
Meroxapol 258	Pluronic 25R8	$HO(CHCH_3CH_2O)_{\sim 18}$-$(CH_2CH_2O)_{\sim 163}$-$(CHCH_3CH_2O)_{\sim 18}OH$	46.1	80°C
Poloxamer 105	Pluronic L35	$HO(CH_2CH_2O)_{\sim 11}$-$(CHCH_3CH_2O)_{\sim 16}$-$(CH_2CH_2O)_{\sim 11}OH$	48.8	77°C
Poloxamer 124	Pluronic L44	$HO(CH_2CH_2O)_{\sim 11}$-$(CHCH_3CH_2O)_{\sim 21}$-$(CH_2CH_2O)_{\sim 11}OH$	45.3	65°C

Other varieties of poloxamer and meroxapol can readily be synthesized using well known techniques. Desirable characteristics are a room temperature surface tension which is as high as possible, and a cloud point between 40°C and 100°C, and preferably between 60°C and 80°C.

Meroxapol $[HO(CHCH_3CH_2O)_x(CH_2CH_2O)_y(CHCH_3CH_2O)_zOH]$ varieties where the average x and z are approximately 4, and the average y is approximately 15 may be suitable.

If salts are used to increase the electrical conductivity of the ink, then the effect of this salt on the cloud point of the surfactant should be considered.

The cloud point of POE surfactants is increased by ions that disrupt water structure (such as I^-), as this makes more water molecules available to form hydrogen bonds with the POE oxygen lone pairs. The cloud point of POE surfactants is decreased by ions that form water structure (such as Cl^-, OH^-), as fewer water molecules are available to form hydrogen bonds. Bromide ions have relatively little effect. The ink composition can be 'tuned' for a desired temperature range by altering the lengths of POE and POP chains in a block copolymer surfactant, and by changing the choice of salts (e.g Cl^- to Br^- to I^-) that are added to increase electrical conductivity. NaCl is likely to be the best choice of salts to increase ink conductivity, due to low cost and non-toxicity. NaCl slightly lowers the cloud point of nonionic surfactants.

<u>Hot Melt Inks</u>

The ink need not be in a liquid state at room temperature. Solid 'hot melt' inks can be used by heating the printing head and ink reservoir above the melting point of the ink. The hot melt ink must be formulated so that the surface tension of the molten ink decreases with temperature. A decrease of approximately 2 mN/m will be typical of many such preparations using waxes and other substances. However, a reduction in surface tension of approximately 20 mN/m is desirable in order to achieve good operating margins when relying on a reduction in surface tension rather than a reduction in viscosity.

The temperature difference between quiescent temperature and drop selection temperature may be greater for a hot melt ink than for a water based ink, as water based inks are constrained by the boiling point of the water.

The ink must be liquid at the quiescent temperature. The quiescent temperature should be higher than the highest ambient temperature likely to be

encountered by the printed page. T he quiescent temperature should also be as low as practical, to reduce the power needed to heat the print head, and to provide a maximum margin between the quiescent and the drop ejection temperatures. A quiescent temperature between 60°C and 90°C is generally suitable, though other temperatures may be used. A drop ejection temperature of between 160°C and 200°C is generally suitable.

There are several methods of achieving an enhanced reduction in surface tension with increasing temperature.

1) A dispersion of microfine particles of a surfactant with a melting point substantially above the quiescent temperature, but substantially below the drop ejection temperature, can be added to the hot melt ink while in the liquid phase.
2) A polar/non-polar microemulsion with a PIT which is preferably at least 20°C above the melting points of both the polar and non-polar compounds.

To achieve a large reduction in surface tension with temperature, it is desirable that the hot melt ink carrier have a relatively large surface tension (above 30 mN/m) when at the quiescent temperature. This generally excludes alkanes such as waxes. Suitable materials will generally have a strong intermolecular attraction, which may be achieved by multiple hydrogen bonds, for example, polyols, such as Hexanetetrol, which has a melting point of 88°C.

Surface tension reduction of various solutions

Figure 3(d) shows the measured effect of temperature on the surface tension of various aqueous preparations containing the following additives:

1) 0.1% sol of Stearic Acid
2) 0.1% sol of Palmitic acid
3) 0.1% solution of Pluronic 10R5 (trade mark of BASF)
4) 0.1% solution of Pluronic L35 (trade mark of BASF)
5) 0.1% solution of Pluronic L44 (trade mark of BASF)

Inks suitable for printing systems of the present invention are described in the following Australian patent specifications, the disclosure of which are hereby incorporated by reference:

'Ink composition based on a microemulsion' (Filing no.: PN5223, filed on 6 September 1995);

'Ink composition containing surfactant sol' (Filing no.: PN5224, filed on 6 September 1995);

'Ink composition for DOD printers with Krafft point near the drop selection temperature sol' (Filing no.: PN6240, filed on 30 October 1995); and

'Dye and pigment in a microemulsion based ink' (Filing no.: PN6241, filed on 30 October 1995).

Operation Using Reduction of Viscosity

As a second example, operation of an embodiment using thermal reduction of viscosity and proximity drop separation, in combination with hot melt ink, is as follows. Prior to operation of the printer, solid ink is melted in the reservoir 64. The reservoir, ink passage to the print head, ink channels 75, and print head 50 are maintained at a temperature at which the ink 100 is liquid, but exhibits a relatively high viscosity (for example, approximately 100 cP). The Ink 100 is retained in the nozzle by the surface tension of the ink. The ink 100 is formulated so that the viscosity of the ink reduces with increasing temperature. The ink pressure oscillates at a frequency which is an integral multiple of the drop ejection frequency from the nozzle. The ink pressure oscillation causes oscillations of the ink meniscus at the nozzle tips, but this oscillation is small due to the high ink viscosity. At the normal operating temperature, these oscillations are of insufficient amplitude to result in drop separation. When the heater 103 is energized, the ink forming the selected drop is heated, causing a reduction in viscosity to a value which is preferably less than 5 cP. The reduced viscosity results in the ink meniscus moving further during the high pressure part of the ink pressure cycle. The recording medium 51 is arranged sufficiently close to the print head 50 so that the selected drops contact the recording medium 51, but sufficiently far away that the unselected

drops do not contact the recording medium 51. Upon contact with the recording medium 51, part of the selected drop freezes, and attaches to the recording medium. As the ink pressure falls, ink begins to move back into the nozzle. The body of ink separates from the ink which is frozen onto the recording medium. The meniscus of the ink 100 at the nozzle tip then returns to low amplitude oscillation. The viscosity of the ink increases to its quiescent level as remaining heat is dissipated to the bulk ink and print head. One ink drop is selected, separated and forms a spot on the recording medium 51 for each heat pulse. As the heat pulses are electrically controlled, drop on demand ink jet operation can be achieved.

Manufacturing of Print Heads

Manufacturing processes for monolithic print heads in accordance with the present invention are described in the following Australian patent specifications filed on 12 April 1995, the disclosure of which are hereby incorporated by reference:

'A monolithic LIFT printing head' (Filing no.: PN2301);

'A manufacturing process for monolithic LIFT printing heads' (Filing no.: PN2302);

'A self-aligned heater design for LIFT print heads' (Filing no.: PN2303);

'Integrated four color LIFT print heads' (Filing no.: PN2304);

'Power requirement reduction in monolithic LIFT printing heads' (Filing no.: PN2305);

'A manufacturing process for monolithic LIFT print heads using anisotropic wet etching' (Filing no.: PN2306);

'Nozzle placement in monolithic drop-on-demand print heads' (Filing no.: PN2307);

'Heater structure for monolithic LIFT print heads' (Filing no.: PN2346);

'Power supply connection for monolithic LIFT print heads' (Filing no.: PN2347);

'External connections for Proximity LIFT print heads' (Filing no.: PN2348); and

'A self-aligned manufacturing process for monolithic LIFT print heads' (Filing no.: PN2349); and

'CMOS process compatible fabrication of LIFT print heads' (Filing no.: PN5222, 6 September 1995).

'A manufacturing process for LIFT print heads with nozzle rim heaters' (Filing no.: PN6238, 30 October 1995);

'A modular LIFT print head' (Filing no.: PN6237, 30 October 1995);

'Method of increasing packing density of printing nozzles' (Filing no.: PN6236, 30 October 1995); and

'Nozzle dispersion for reduced electrostatic interaction between simultaneously printed droplets' (Filing no.: PN6239, 30 October 1995).

Control of Print Heads

Means of providing page image data and controlling heater temperature in print heads of the present invention is described in the following Australian patent specifications filed on 12 April 1995, the disclosure of which are hereby incorporated by reference:

'Integrated drive circuitry in LIFT print heads' (Filing no.: PN2295);

'A nozzle clearing procedure for Liquid Ink Fault Tolerant (LIFT) printing' (Filing no.: PN2294);

'Heater power compensation for temperature in LIFT printing systems' (Filing no.: PN2314);

'Heater power compensation for thermal lag in LIFT printing systems' (Filing no.: PN2315);

'Heater power compensation for print density in LIFT printing systems' (Filing no.: PN2316);

'Accurate control of temperature pulses in printing heads' (Filing no.: PN2317);

'Data distribution in monolithic LIFT print heads' (Filing no.: PN2318);

'Page image and fault tolerance routing device for LIFT printing systems' (Filing no.: PN2319); and

'A removable pressurized liquid ink cartridge for LIFT printers' (Filing no.: PN2320).

Image Processing for Print Heads

An objective of printing systems according to the invention is to attain a print quality which is equal to that which people are accustomed to in quality color publications printed using offset printing. This can be achieved using a print resolution of approximately 1,600 dpi. However, 1,600 dpi printing is difficult and expensive to achieve. Similar results can be achieved using 800 dpi printing, with 2 bits per pixel for cyan and magenta, and one bit per pixel for yellow and black. This color model is herein called CC'MM'YK. Where high quality monochrome image printing is also required, two bits per pixel can also be used for black. This color model is herein called CC'MM'YKK'. Color models, halftoning, data compression, and real-time expansion systems suitable for use in systems of this invention and other printing systems are described in the following Australian patent specifications filed on 12 April 1995, the disclosure of which are hereby incorporated by reference:

'Four level ink set for bi-level color printing' (Filing no.: PN2339);

'Compression system for page images' (Filing no.: PN2340);

'Real-time expansion apparatus for compressed page images' (Filing no.: PN2341); and

'High capacity compressed document image storage for digital color printers' (Filing no.: PN2342);

'Improving JPEG compression in the presence of text' (Filing no.: PN2343);

'An expansion and halftoning device for compressed page images' (Filing no.: PN2344); and

'Improvements in image halftoning' (Filing no.: PN2345).

Applications Using Print Heads According to this Invention

Printing apparatus and methods of this invention are suitable for a wide range of applications, including (but not limited to) the following: color and monochrome office printing, short run digital printing, high speed digital printing, process color printing, spot color printing, offset press supplemental printing, low cost printers using scanning print heads, high speed printers using pagewidth print heads, portable color and monochrome printers, color and monochrome copiers, color and monochrome facsimile machines, combined printer, facsimile and copying machines, label printing, large format plotters, photographic duplication, printers for digital photographic processing, portable printers incorporated into digital 'instant' cameras, video printing, printing of PhotoCD images, portable printers for 'Personal Digital Assistants', wallpaper printing, indoor sign printing, billboard printing, and fabric printing.

Printing systems based on this invention are described in the following Australian patent specifications filed on 12 April 1995, the disclosure of which are hereby incorporated by reference:

'A high speed color office printer with a high capacity digital page image store' (Filing no.: PN2329);

'A short run digital color printer with a high capacity digital page image store' (Filing no.: PN2330);

'A digital color printing press using LIFT printing technology' (Filing no.: PN2331);

'A modular digital printing press' (Filing no.: PN2332);

'A high speed digital fabric printer' (Filing no.: PN2333);

'A color photograph copying system' (Filing no.: PN2334);

'A high speed color photocopier using a LIFT printing system' (Filing no.: PN2335);

'A portable color photocopier using LIFT printing technology' (Filing no.: PN2336);

'A photograph processing system using LIFT printing technology' (Filing no.: PN2337);

'A plain paper facsimile machine using a LIFT printing system' (Filing no.: PN2338);

'A PhotoCD system with integrated printer' (Filing no.: PN2293);

'A color plotter using LIFT printing technology' (Filing no.: PN2291);

'A notebook computer with integrated LIFT color printing system' (Filing no.: PN2292);

'A portable printer using a LIFT printing system' (Filing no.: PN2300);

'Fax machine with on-line database interrogation and customized magazine printing' (Filing no.: PN2299);

'Miniature portable color printer' (Filing no.: PN2298);

'A color video printer using a LIFT printing system' (Filing no.: PN2296); and

'An integrated printer, copier, scanner, and facsimile using a LIFT printing system' (Filing no.: PN2297)

Compensation of Print Heads for Environmental Conditions

It is desirable that drop on demand printing systems have consistent and predictable ink drop size and position. Unwanted variation in ink drop size and position causes variations in the optical density of the resultant print, reducing the perceived print quality. These variations should be kept to a small proportion of the nominal ink drop volume and pixel spacing respectively. Many environmental variables can be compensated to reduce their effect to insignificant levels. Active compensation of some factors can be achieved by varying the power applied to the nozzle heaters.

An optimum temperature profile for one print head embodiment involves an instantaneous raising of the active region of the nozzle tip to the ejection temperature, maintenance of this region at the ejection temperature for the duration of the pulse, and instantaneous cooling of the region to the ambient temperature.

This optimum is not achievable due to the stored heat capacities and thermal conductivities of the various materials used in the fabrication of the nozzles

in accordance with the invention. However, improved performance can be achieved by shaping the power pulse using curves which can be derived by iterative refinement of finite element simulation of the print head. The power applied to the heater can be varied in time by various techniques, including, but not limited to:

1) Varying the voltage applied to the heater
2) Modulating the width of a series of short pulses (PWM)
3) Modulating the frequency of a series of short pulses (PFM)

To obtain accurate results, a transient fluid dynamic simulation with free surface modeling is required, as convection in the ink, and ink flow, significantly affect on the temperature achieved with a specific power curve.

By the incorporation of appropriate digital circuitry on the print head substrate, it is practical to individually control the power applied to each nozzle. One way to achieve this is by 'broadcasting' a variety of different digital pulse trains across the print head chip, and selecting the appropriate pulse train for each nozzle using multiplexing circuits.

An example of the environmental factors which may be compensated for is listed in the table "Compensation for environmental factors". This table identifies which environmental factors are best compensated globally (for the entire print head), per chip (for each chip in a composite multi-chip print head), and per nozzle.

Compensation for environmental factors

Factor compensated	Scope	Sensing or user control method	Compensation mechanism
Ambient Temperature	Global	Temperature sensor mounted on print head	Power supply voltage or global PFM patterns
Power supply voltage fluctuation with number of active nozzles	Global	Predictive active nozzle count based on print data	Power supply voltage or global PFM patterns
Local heat build-up with successive nozzle actuation	Per nozzle	Predictive active nozzle count based on print data	Selection of appropriate PFM pattern for each printed drop

Drop size control for multiple bits per pixel	Per nozzle	Image data	Selection of appropriate PFM pattern for each printed drop
Nozzle geometry variations between wafers	Per chip	Factory measurement, datafile supplied with print head	Global PFM patterns per print head chip
Heater resistivity variations between wafers	Per chip	Factory measurement, datafile supplied with print head	Global PFM patterns per print head chip
User image intensity adjustment	Global	User selection	Power supply voltage, electrostatic acceleration voltage, or ink pressure
Ink surface tension reduction method and threshold temperature	Global	Ink cartridge sensor or user selection	Global PFM patterns
Ink viscosity	Global	Ink cartridge sensor or user selection	Global PFM patterns and/or clock rate
Ink dye or pigment concentration	Global	Ink cartridge sensor or user selection	Global PFM patterns
Ink response time	Global	Ink cartridge sensor or user selection	Global PFM patterns

Most applications will not require compensation for all of these variables. Some variables have a minor effect, and compensation is only necessary where very high image quality is required.

Print head drive circuits

Figure 4 is a block schematic diagram showing electronic operation of an example head driver circuit in accordance with this invention. This control circuit uses analog modulation of the power supply voltage applied to the print head to achieve heater power modulation, and does not have individual control of the power applied to each nozzle. Figure 4 shows a block diagram for a system using an 800 dpi pagewidth print head which prints process color using the CC'MM'YK

color model. The print head 50 has a total of 79,488 nozzles, with 39,744 main nozzles and 39,744 redundant nozzles. The main and redundant nozzles are divided into six colors, and each color is divided into 8 drive phases. Each drive phase has a shift register which converts the serial data from a head control ASIC 400 into parallel data for enabling heater drive circuits. There is a total of 96 shift registers, each providing data for 828 nozzles. Each shift register is composed of 828 shift register stages 217, the outputs of which are logically anded with phase enable signal by a nand gate 215. The output of the nand gate 215 drives an inverting buffer 216, which in turn controls the drive transistor 201. The drive transistor 201 actuates the electrothermal heater 200, which may be a heater 103 as shown in figure 1(b). To maintain the shifted data valid during the enable pulse, the clock to the shift register is stopped the enable pulse is active by a clock stopper 218, which is shown as a single gate for clarity, but is preferably any of a range of well known glitch free clock control circuits. Stopping the clock of the shift register removes the requirement for a parallel data latch in the print head, but adds some complexity to the control circuits in the Head Control ASIC 400. Data is routed to either the main nozzles or the redundant nozzles by the data router 219 depending on the state of the appropriate signal of the fault status bus.

The print head shown in figure 4 is simplified, and does not show various means of improving manufacturing yield, such as block fault tolerance. Drive circuits for different configurations of print head can readily be derived from the apparatus disclosed herein.

Digital information representing patterns of dots to be printed on the recording medium is stored in the Page or Band memory 1513, which may be the same as the Image memory 72 in figure 1(a). Data in 32 bit words representing dots of one color is read from the Page or Band memory 1513 using addresses selected by the address mux 417 and control signals generated by the Memory Interface 418. These addresses are generated by Address generators 411, which forms part of the 'Per color circuits' 410, for which there is one for each of the six color components. The addresses are generated based on the positions of the nozzles in relation to the

print medium. As the relative position of the nozzles may be different for different print heads, the Address generators 411 are preferably made programmable. The Address generators 411 normally generate the address corresponding to the position of the main nozzles. However, when faulty nozzles are present, locations of blocks of nozzles containing faults can be marked in the Fault Map RAM 412. The Fault Map RAM 412 is read as the page is printed. If the memory indicates a fault in the block of nozzles, the address is altered so that the Address generators 411 generate the address corresponding to the position of the redundant nozzles. Data read from the Page or Band memory 1513 is latched by the latch 413 and converted to four sequential bytes by the multiplexer 414. Timing of these bytes is adjusted to match that of data representing other colors by the FIFO 415. This data is then buffered by the buffer 430 to form the 48 bit main data bus to the print head 50. The data is buffered as the print head may be located a relatively long distance from the head control ASIC. Data from the Fault Map RAM 412 also forms the input to the FIFO 416. The timing of this data is matched to the data output of the FIFO 415, and buffered by the buffer 431 to form the fault status bus.

The programmable power supply 320 provides power for the head 50. The voltage of the power supply 320 is controlled by the DAC 313, which is part of a RAM and DAC combination (RAMDAC) 316. The RAMDAC 316 contains a dual port RAM 317. The contents of the dual port RAM 317 are programmed by the Microcontroller 315. Temperature is compensated by changing the contents of the dual port RAM 317. These values are calculated by the microcontroller 315 based on temperature sensed by a thermal sensor 300. The thermal sensor 300 signal connects to the Analog to Digital Converter (ADC) 311. The ADC 311 is preferably incorporated in the Microcontroller 315.

The Head Control ASIC 400 contains control circuits for thermal lag compensation and print density. Thermal lag compensation requires that the power supply voltage to the head 50 is a rapidly time-varying voltage which is synchronized with the enable pulse for the heater. This is achieved by programming the programmable power supply 320 to produce this voltage. An analog time

varying programming voltage is produced by the DAC 313 based upon data read from the dual port RAM 317. The data is read according to an address produced by the counter 403. The counter 403 produces one complete cycle of addresses during the period of one enable pulse. This synchronization is ensured, as the counter 403 is clocked by the system clock 408, and the top count of the counter 403 is used to clock the enable counter 404. The count from the enable counter 404 is then decoded by the decoder 405 and buffered by the buffer 432 to produce the enable pulses for the head 50. The counter 403 may include a prescaler if the number of states in the count is less than the number of clock periods in one enable pulse. Sixteen voltage states are adequate to accurately compensate for the heater thermal lag. These sixteen states can be specified by using a four bit connection between the counter 403 and the dual port RAM 317. However, these sixteen states may not be linearly spaced in time. To allow non-linear timing of these states the counter 403 may also include a ROM or other device which causes the counter 403 to count in a non-linear fashion. Alternatively, fewer than sixteen states may be used.

For print density compensation, the printing density is detected by counting the number of pixels to which a drop is to be printed ('on' pixels) in each enable period. The 'on' pixels are counted by the On pixel counters 402. There is one On pixel counter 402 for each of the eight enable phases. The number of enable phases in a print head in accordance with the invention depend upon the specific design. Four, eight, and sixteen are convenient numbers, though there is no requirement that the number of enable phases is a power of two. The On Pixel Counters 402 can be composed of combinatorial logic pixel counters 420 which determine how many bits in a nibble of data are on. This number is then accumulated by the adder 421 and accumulator 422. A latch 423 holds the accumulated value valid for the duration of the enable pulse. The multiplexer 401 selects the output of the latch 423 which corresponds to the current enable phase, as determined by the enable counter 404. The output of the multiplexer 401 forms part of the address of the dual port RAM 317. An exact count of the number of 'on' pixels is not necessary, and the most significant four bits of this count are adequate.

Combining the four bits of thermal lag compensation address and the four bits of print density compensation address means that the dual port RAM 317 has an 8 bit address. This means that the dual port RAM 317 contains 256 numbers, which are in a two dimensional array. These two dimensions are time (for thermal lag compensation) and print density. A third dimension - temperature - can be included. As the ambient temperature of the head varies only slowly, the microcontroller 315 has sufficient time to calculate a matrix of 256 numbers compensating for thermal lag and print density at the current temperature. Periodically (for example, a few times a second), the microcontroller senses the current head temperature and calculates this matrix.

The clock to the print head 50 is generated from the system clock 408 by the Head clock generator 407, and buffered by the buffer 406. To facilitate testing of the Head control ASIC, JTAG test circuits 499 may be included.

Comparison with thermal ink jet technology

The table "Comparison between Thermal ink jet and Present Invention" compares the aspects of printing in accordance with the present invention with thermal ink jet printing technology.

A direct comparison is made between the present invention and thermal ink jet technology because both are drop on demand systems which operate using thermal actuators and liquid ink. Although they may appear similar, the two technologies operate on different principles.

Thermal ink jet printers use the following fundamental operating principle. A thermal impulse caused by electrical resistance heating results in the explosive formation of a bubble in liquid ink. Rapid and consistent bubble formation can be achieved by superheating the ink, so that sufficient heat is transferred to the ink before bubble nucleation is complete. For water based ink, ink temperatures of approximately 280°C to 400°C are required. The bubble formation causes a pressure wave which forces a drop of ink from the aperture with high velocity. The bubble then collapses, drawing ink from the ink reservoir to re-fill the nozzle. Thermal ink jet printing has been highly successful commercially due to the high

nozzle packing density and the use of well established integrated circuit manufacturing techniques. However, thermal ink jet printing technology faces significant technical problems including multi-part precision fabrication, device yield, image resolution, 'pepper' noise, printing speed, drive transistor power, waste power dissipation, satellite drop formation, thermal stress, differential thermal expansion, kogation, cavitation, rectified diffusion, and difficulties in ink formulation.

Printing in accordance with the present invention has many of the advantages of thermal ink jet printing, and completely or substantially eliminates many of the inherent problems of thermal ink jet technology.

Comparison between Thermal ink jet and Present Invention

	Thermal Ink-Jet	Present Invention
Drop selection mechanism	Drop ejected by pressure wave caused by thermally induced bubble	Choice of surface tension or viscosity reduction mechanisms
Drop separation mechanism	Same as drop selection mechanism	Choice of proximity, electrostatic, magnetic, and other methods
Basic ink carrier	Water	Water, microemulsion, alcohol, glycol, or hot melt
Head construction	Precision assembly of nozzle plate, ink channel, and substrate	Monolithic
Per copy printing cost	Very high due to limited print head life and expensive inks	Can be low due to permanent print heads and wide range of possible inks
Satellite drop formation	Significant problem which degrades image quality	No satellite drop formation
Operating ink temperature	280°C to 400°C (high temperature limits dye use and ink formulation)	Approx. 70°C (depends upon ink formulation)

Peak heater temperature	400°C to 1,000°C (high temperature reduces device life)	Approx. 130°C
Cavitation (heater erosion by bubble collapse)	Serious problem limiting head life	None (no bubbles are formed)
Kogation (coating of heater by ink ash)	Serious problem limiting head life and ink formulation	None (water based ink temperature does not exceed 100°C)
Rectified diffusion (formation of ink bubbles due to pressure cycles)	Serious problem limiting ink formulation	Does not occur as the ink pressure does not go negative
Resonance	Serious problem limiting nozzle design and repetition rate	Very small effect as pressure waves are small
Practical resolution	Approx. 800 dpi max.	Approx. 1,600 dpi max.
Self-cooling operation	No (high energy required)	Yes: printed ink carries away drop selection energy
Drop ejection velocity	High (approx. 10 m/sec)	Low (approx. 1 m/sec)
Crosstalk	Serious problem requiring careful acoustic design, which limits nozzle refill rate.	Low velocities and pressures associated with drop ejection make crosstalk very small.
Operating thermal stress	Serious problem limiting print-head life.	Low: maximum temperature increase approx. 90°C at centre of heater.
Manufacturing thermal stress	Serious problem limiting print-head size.	Same as standard CMOS manufacturing process.
Drop selection energy	Approx. 20 μJ	Approx. 270 nJ
Heater pulse period	Approx. 2-3 μs	Approx. 15-30 μs
Average heater pulse power	Approx. 8 Watts per heater.	Approx. 12 mW per heater. This is more than 500 times less than Thermal Ink-Jet.
Heater pulse voltage	Typically approx. 40V.	Approx. 5 to 10V.

Heater peak pulse current	Typically approx. 200 mA per heater. This requires bipolar or very large MOS drive transistors.	Approx. 4 mA per heater. This allows the use of small MOS drive transistors.
Fault tolerance	Not implemented. Not practical for edge shooter type.	Simple implementation results in better yield and reliability
Constraints on ink composition	Many constraints including kogation, nucleation, etc.	Temperature coefficient of surface tension or viscosity must be negative.
Ink pressure	Atmospheric pressure or less	Approx. 1.1 atm
Integrated drive circuitry	Bipolar circuitry usually required due to high drive current	CMOS, nMOS, or bipolar
Differential thermal expansion	Significant problem for large print heads	Monolithic construction reduces problem
Pagewidth print heads	Major problems with yield, cost, precision construction, head life, and power dissipation	High yield, low cost and long life due to fault tolerance. Self cooling due to low power dissipation.

Yield and Fault Tolerance

In most cases, monolithic integrated circuits cannot be repaired if they are not completely functional when manufactured. The percentage of operational devices which are produced from a wafer run is known as the yield. Yield has a direct influence on manufacturing cost. A device with a yield of 5% is effectively ten times more expensive to manufacture than an identical device with a yield of 50%.

There are three major yield measurements:

1) Fab yield
2) Wafer sort yield
3) Final test yield

For large die, it is typically the wafer sort yield which is the most serious limitation on total yield. Full pagewidth color heads in accordance with this

invention are very large in comparison with typical VLSI circuits. Good wafer sort yield is critical to the cost-effective manufacture of such heads.

Figure 5 is a graph of wafer sort yield versus defect density for a monolithic full width color A4 head embodiment of the invention. The head is 215 mm long by 5 mm wide. The non fault tolerant yield 198 is calculated according to Murphy's method, which is a widely used yield prediction method. With a defect density of one defect per square cm, Murphy's method predicts a yield less than 1%. This means that more than 99% of heads fabricated would have to be discarded. This low yield is highly undesirable, as the print head manufacturing cost becomes unacceptably high.

Murphy's method approximates the effect of an uneven distribution of defects. Figure 5 also includes a graph of non fault tolerant yield 197 which explicitly models the clustering of defects by introducing a defect clustering factor. The defect clustering factor is not a controllable parameter in manufacturing, but is a characteristic of the manufacturing process. The defect clustering factor for manufacturing processes can be expected to be approximately 2, in which case yield projections closely match Murphy's method.

A solution to the problem of low yield is to incorporate fault tolerance by including redundant functional units on the chip which are used to replace faulty functional units.

In memory chips and most Wafer Scale Integration (WSI) devices, the physical location of redundant sub-units on the chip is not important. However, in printing heads the redundant sub-unit may contain one or more printing actuators. These must have a fixed spatial relationship to the page being printed. To be able to print a dot in the same position as a faulty actuator, redundant actuators must not be displaced in the non-scan direction. However, faulty actuators can be replaced with redundant actuators which are displaced in the scan direction. To ensure that the redundant actuator prints the dot in the same position as the faulty actuator, the data timing to the redundant actuator can be altered to compensate for the displacement in the scan direction.

To allow replacement of all nozzles, there must be a complete set of spare nozzles, which results in 100% redundancy. The requirement for 100% redundancy would normally more than double the chip area, dramatically reducing the primary yield before substituting redundant units, and thus eliminating most of the advantages of fault tolerance.

However, with print head embodiments according to this invention, the minimum physical dimensions of the head chip are determined by the width of the page being printed, the fragility of the head chip, and manufacturing constraints on fabrication of ink channels which supply ink to the back surface of the chip. The minimum practical size for a full width, full color head for printing A4 size paper is approximately 215 mm x 5 mm. This size allows the inclusion of 100% redundancy without significantly increasing chip area, when using 1.5 μm CMOS fabrication technology. Therefore, a high level of fault tolerance can be included without significantly decreasing primary yield.

When fault tolerance is included in a device, standard yield equations cannot be used. Instead, the mechanisms and degree of fault tolerance must be specifically analyzed and included in the yield equation. Figure 5 shows the fault tolerant sort yield 199 for a full width color A4 head which includes various forms of fault tolerance, the modeling of which has been included in the yield equation. This graph shows projected yield as a function of both defect density and defect clustering. The yield projection shown in figure 5 indicates that thoroughly implemented fault tolerance can increase wafer sort yield from under 1% to more than 90% under identical manufacturing conditions. This can reduce the manufacturing cost by a factor of 100.

Fault tolerance is highly recommended to improve yield and reliability of print heads containing thousands of printing nozzles, and thereby make pagewidth printing heads practical. However, fault tolerance is not to be taken as an essential part of the present invention.

Fault tolerance in drop-on-demand printing systems is described in the following Australian patent specifications filed on 12 April 1995, the disclosure of which are hereby incorporated by reference:

'Integrated fault tolerance in printing mechanisms' (Filing no.: PN2324);

'Block fault tolerance in integrated printing heads' (Filing no.: PN2325);

'Nozzle duplication for fault tolerance in integrated printing heads' (Filing no.: PN2326);

'Detection of faulty nozzles in printing heads' (Filing no.: PN2327); and

'Fault tolerance in high volume printing presses' (Filing no.: PN2328).

Video printers using concurrent drop selection and drop separation print heads

The table "Example product specifications," shows the specifications of one possible configuration of a color video printer using concurrent drop selection and drop separation printing technology.

Example product specifications

Configuration	Portable, small format
Printer type	Full width printing head
Number of nozzles	9,440 active nozzles, 9,440 spare nozzles
Print size	150 mm X 100 mm
Print speed	1 second
Printer resolution	600 dpi, digitally halftoned
Video formats	PAL, NTSC (Composite and S-Video)
Video processing	Digital (DSP)
Video memory	Full frame (1 MByte)
Dimensions (W X D X H)	Approx. 140 X 200 X 200 mm
Color calibration	Automatic

The table "LIFT head type Photo-4-600" is a summary of some characteristics of an example full color monolithic printing head capable of printing a photograph size image at 600 dpi in one second.

Figure 6 shows a schematic process diagram of a video printer using concurrent drop selection and drop separation printing technology. The blocks in this diagram represent discrete functions, irrespective of their implementations. Some of the blocks are electronic hardware, some are computer software, some are electromechanical units, and some are mechanical units. Some of the blocks are subsystems, which may include electronic hardware, software, mechanics, and optics.

The image to be printed derives from a video source 525. This video source may be in any video format, including PAL, NTSC, S-Video, RGB component video, CCIR601 digital video, or MAC. High resolution video sources, such as HDTV, may also be used. Computer video formats, such as VGA, SVGA, and workstation video outputs may also be used. Each video format requires conversion into a format suitable for storage in the digital frame store 529. This conversion is accomplished by the use of a video digitizer 526 and digital video decoder 527. For PAL and NTSC television, the Philips TDA8708 is a suitable device for the video digitizer, and a Philips SAA7197 is a suitable digital decoder. Alternative configurations are possible. For example, an analog decoder may be used. The output of this analog decoder may then be digitized using an analog to digital converter. If a direct digital video connection is used, then no analog to digital converter is required. Various video formats do not require a video decoder. An example is RGB component video, or analog RGB outputs from personal computers and workstations. In this case, only the video digitizer function is required. The design of systems for video digitizing is well known. The output of the video digitizer is raster format continuous tone image data, which may be in a 16 bit per pixel Y,Cr,Cb format, or a 24 bit RGB format, or other suitable frame storage format.

A single frame of digital video image information is stored in the digital frame store 529 at the user's request. This information may then optionally be processed by a digital image processing function 528. The digital image processing is not required to be a real-time process, so may readily be performed in

software using a microprocessor. This microprocessor may be the control microcomputer 511, or may be a separate processor. If very high image processing speed is required, then the digital image processing functions may be performed by digital electronic hardware, which may be in the form of ASICs. Alternatively, a combination of digital electronic hardware and software may be used. This approach retains the high performance of a digital hardware implementation, and the flexibility of a software implementation. There are many image processing functions which may be performed by the digital image processing unit 528. If the video source 525 is interlaced, then the digital removal of inter-field motion is desirable. The image may be digitally filtered to enhance edges and suppress video noise. The image may be color corrected, and adjusted for brightness and contrast. Special effects and image filters may be applied. Such techniques are well known in the digital video equipment industry.

After the digital image processing is complete, the image is ready for printing. The image data is read from the digital frame store 529 and digitally halftoned by the vector error diffusion unit 504. A vector error diffusion algorithm is used to achieve a high image quality. This operates by selecting the closest printable color in three dimensional color space to the desired Color. The difference between the desired Color and this printable color is determined. This difference is then diffused to neighboring pixels. The vector error diffusion unit 504 accepts a raster ordered continuous tone input image and generates a bi-level output with 4 bits per pixel (one bit for each of cyan, magenta, yellow, and grey). Alternatively, the color components can be independently error diffused, although this provides an image of substantially lower quality. It is also possible to dither the continuous tone image to obtain a bi-level image. In this case, a computer optimized dispersed dot ordered dither is recommended.

In most color process printing, the colors cyan, magenta, yellow, and black (CMYK) are used. In this case, image quality can be improved by substituting a 50 percent density neutral grey ink for the black ink. This substitution can be made because the video images to be printed will typically not contain small sized

black text, therefore a single-ink black is not required. The use of grey ink provides a better color distribution of the sixteen available ink combinations in a pixel. This improved color distribution can be used to reduce the visual noise resulting from the halftoning process.

This data is then processed by the data phasing and fault tolerance system 506. This unit provides the appropriate delays to synchronize the print data with the offset positions of the nozzle of the printing head. It also provides alternate data paths for fault tolerance, to compensate for blocked nozzles, faulty nozzles or faulty circuits in the print head.

The monolithic printing head 50 prints the image 60 composed of a multitude of ink drops onto a recording medium 51. This medium will typically be paper, but can also be overhead transparency film, cloth, or most other substantially flat surfaces which will accept ink drops.

The bi-level image processed by the data phasing and fault tolerance circuit 506 provides the pixel data in the correct sequence to the data shift registers 56. Data sequencing is required to compensate for the nozzle arrangement and the movement of the paper. When the data has been loaded into the shift registers, it is presented in parallel to the heater driver circuits 57. At the correct time, these driver circuits will electronically connect the corresponding heaters 58 with the voltage pulse generated by the pulse shaper circuit 61 and the voltage regulator 62. The heaters 58 heat the tip of the nozzles 59, reducing the attraction of the ink to the nozzle surface material. Ink drops 60 escape from the nozzles in a pattern which corresponds to the digital impulses which have been applied to the heater driver circuits. The pressure of the ink in the nozzle is important, and the pressure in the ink reservoir 64 is regulated by the pressure regulator 63. The ink drops 60 fall under the influence of gravity or another field type towards the paper 51. During printing, the paper is continually moved relative to the print head by the paper transport system 65. As the print head is the full width of the paper used, it is only necessary to move the paper in one direction, and the print head can remain fixed. The paper may be supplied as pre-cut sheets, in which case the paper transport

mechanism must acquire and transport the sheets individually past the printing head. Alternatively, the paper may be provided in rolls. In this case, an automatic paper cutting blade is required.

The various subsystems are coordinated under the control of one or more control microcomputers 511, which also provide the user interface of the system.

PhotoCD printers using print heads

The table "Example product specifications," the specifications of one possible configuration of a PhotoCD player with integrated color printer based on LIFT technology.

Example product specifications

Configuration	Portable, table-top
Printer type	LIFT full width printing head
Image source	PhotoCD images stored on CDROM
Number of nozzles	18,880 active nozzles, 18,880 spare nozzles
Print sizes	150 mm X 100 mm
Print speed	1 second
Printer resolution	800 dpi, digitally halftoned
Image processing	Digital
Dimensions (W X D X H)	Approx. 140 X 200 X 200 mm
Connectivity	Optional

The table "LIFT head type Photo-6-800" is a summary of some characteristics of an example full color monolithic printing head capable of printing a photograph size image at 600 dpi in one second.

Figure 6 shows a schematic process diagram of a PhotoCD player incorporating a color printer using a printing head. The blocks in this diagram represent discrete functions, irrespective of their implementations. Some of the blocks are electronic hardware, some are computer software, some are electromechanical units, and some are mechanical units. Some of the blocks are

subsystems, which may include electronic hardware, software, mechanics, and optics.

A major unit in the system is the main processor 590. This is a microprocessor, and may be any of a wide variety of microprocessors from several different manufacturers. The main processor 590 executes computer programs such as image decompression and digital halftoning. It also executes a program providing the user interface to the system.

The television or monitor 594 is a standard video display unit. This is used for viewing the digitally stored photographs prior to printing them. This unit would typically not be supplied with the PhotoCD player, but instead would be supplied by the user.

A CD-ROM drive 592 is used to access data stored on a PhotoCD encoded digital compact disk. The data stored on the disk is primarily in the form of digitally encoded images. For each image, several image sizes are stored. Low resolution index images are stored to allow rapid selection of an image to view. Television resolution images 596 are also stored. These are representations of the photographs stored at sufficient resolution to obtain a high quality image on a television set. When images are to be viewed on a television set, the image data is read from the PhotoCD using the CD-ROM drive 592. This image data is stored in a video frame store 598, consisting of semiconductor memory, timing circuits, data paths, and address generators. High resolution images 597 are also stored on the PhotoCD. These are stored in digitally compressed form to reduce the time required to access an image, and to increase the number of images that may be stored on a single PhotoCD disc. These images must be decompressed by an image decompression unit 595 before being viewed or printed. The image decompression unit 595 may be implemented either as software running on the main processor 580, or as an ASIC or other digital hardware implementation.

When a photographic image is to be printed, a print resolution digital image 597 of the photograph is read from the PhotoCD. This data is decompressed by the image decompression unit 595, and digitally halftoned by the digital

halftoning unit 515. The data is then stored in the bi-level image memory 505. To reduce the memory requirements of the system, the image data is not stored directly after the decompression process. Instead, decompression and digital halftoning occur simultaneously, or in an interleaved manner using a small memory buffer.

For highest quality, the digital halftoning unit 515 can implement a vector error diffusion algorithm. This operates by selecting the closest printable color in three dimensional color space to the desired Color. The difference between the desired Color and this printable color is determined. This difference is then diffused to neighboring pixels. The digital halftoning unit 515 accepts a raster ordered continuous tone (typically 24 bit per pixel) input image and generates a bi-level output with 4 bits per pixel (one bit for each of Cyan, Magenta, Yellow, and black). This is then stored in the bi-level image memory 505.

When a page is to be printed, the Bi-level image memory 505 is read in real-time. This data is then processed by the data phasing and fault tolerance system 506. The various subsystems are coordinated by the main processor 580, or by one or more slave microcontrollers.

Physical configuration

There are many possible physical configurations of the invention.

Figure 7(a) shows a top view of video printer, showing the control buttons 901 and the top edge of the paper and ink cartridge 910.

Figure 7(b) shows the same printer from side view. The paper and ink cartridge 910 is inserted into the printer so the paper is in contact with the paper pick-up roller 912. When a video image is to be printed, a pre-cut sheet of paper is picked up from the paper and ink cartridge 910 by the paper pick-up roller 912 and moved to the paper transport rollers 65. It is then passed beneath the printing head 50, which prints an image derived from the captured video frame. The printed sheet 51 is ejected from the front of the device. The video capture, image processing, print-head control, and other circuitry is contained on a circuit board 900. The user controls the device by pressing control buttons 901.

Figure 8 shows a perspective view of the printer, showing the control buttons 901 and the top edge of the paper and ink cartridge 910.

The foregoing describes one embodiment of the present invention. Modifications, obvious to those skilled in the art, can be made thereto without departing from the scope of the invention.

Appendix A

LIFT head type Photo-4-600

This is a four color print head for photograph (150mm x 100 mm) printing. Resolution is 600 dpi bi-level for medium quality output. This print head can also be used for A6 printing, or as a part of larger printheads.

Basic specifications		Derivation
Resolution	600 dpi	*Specification*
Print head length	105 mm	*Width of print area, plus 5 mm*
Print head width	5 mm	*Derived from physical and layout constraints of head*
Ink colors	4	*CMYK*
Page size	Photo	*Specification*
Print area width	100 mm	*Pixels per line / Resolution*
Print area length	150 mm	*Total length of active printing*
Page printing time	0.7 seconds	*Derived from scans, lines per page and dot printing rate*
Pages per minute	74 ppm	*60 /(120% of print time in seconds)*
Basic IC process	2 micron CMOS	*Recommendation*
Bitmap memory requirement	4.0 MBytes	*Bitmap memory required for one scan (cannot pause)*
Pixel spacing	42.3 μm	*Reciprocal of resolution*
Pixels per line	2,360	*Active nozzles / Number of colors*
Lines per page	3,543	*Scan distance times resolution*
Pixels per page	8,361,480	*Pixels per line times lines per page*
Drops per page	33,445,920	*Pixels per page times simultaneous ink colors*
Average data rate	5.9 MBytes/sec	*Pixels per second * ink colors / 8 MBits*
Ejection energy per drop	1,587 nJ	*Energy applied to heater in finite element simulations*
Energy to print full black page	53 J	*Drop ejection energy times drops per page*
Recording medium speed	22.0 cm/sec	*1/(resolution times actuation period times phases)*

Yield and cost		Derivation
Number of chips per head	1	*Recommendation*
Wafer size	150 mm (6")	*Recommendation*
Chips per wafer	24	*From chip size and recommended wafer size*
Print head chip area	5.2 cm^2	*Chip width times length*
Yield without fault tolerance	3.60%	*Using Murphy's method, defect density = 1 per cm^2*
Yield with fault tolerance	92%	*See fault tolerant yield calculations ($D=1/cm^2$, CF=2)*
Functional print heads per month	221,544	*Assuming 10,000 wafer starts per month*
Print head assembly cost	$4	*Estimate*
Factory overhead per print head	$15	*Based on $120m. cost for refurbished 1.5 μm Fab line amortised over 5 years, plus $16m. P.A. operating cost*
Wafer cost per print head	$14	*Based on materials cost of $300 per wafer*
Approx. total print head cost	$33	*Sum of print head assembly, overhead, and wafer costs*

Appendix A (cont'd.)

LIFT head type Photo-4-600

Nozzle and actuation specifications		Derivation
Nozzle radius	14 μm	*Specification*
Number of actuation phases	8	*Specification*
Nozzles per phase	1,180	*From page width, resolution and colors*
Active nozzles per head	9,440	*Actuation phases times nozzles per phase*
Redundant nozzles per head	9,440	*Same as active nozzles for 100% redundancy*
Total nozzles per head	18,880	*Active plus redundant nozzles*
Drop rate per nozzle	5,208 Hz	*1/(heater active period times number of phases)*
Heater radius	14.5 μm	*From nozzle geometry and radius*
Heater thin film resistivity	2.3 μΩm	*For heater formed from TaAl*
Heater resistance	2,095 Ω	*From heater dimensions and resistivity*
Average heater pulse current	5.6 mA	*From heater power and resistance*
Heater active period	24 μs	*From finite element simulations*
Settling time petween pulses	168 μs	*Active period * (actuation phases-1)*
Clock pulses per line	1,349	*Assuming multiple clocks and no transfer register*
Clock frequency	7.0 MHz	*From clock pulses per line, and lines per second*
Drive transistor on resistance	42 Ω	*From recommended device geometry*
Average head drive voltage	12.0 V	*Heater current * (heater +drive transistor resistance)*
Drop selection temperature	50 °C	*Temperature at which critical surface tension is reached*
Heater peak temperature	120 °C	*From finite element simulations*

Ink specifications		Derivation
Basic ink carrier	Water	*Specification*
Surfactant	1-Hexadecanol	*Suggested method of achieving temperature threshold*
Ink drop volume	18 pl	*From finite element simulations*
Ink density	1.030 g/cm³	*Black ink density at 60°C*
Ink drop mass	18.5 ng	*Ink drop volume times ink density*
Ink specific heat capacity	4.2 J/Kg/°C	*Ink carrier characteristic*
Max. energy for self cooling	2.327 nJ/drop	*Ink drop heat capacity times temperature increase*
Total ink per color per page	0.15 ml	*Drops per page per color times drop volume*
Maximum ink flow rate per color	0.22 ml/sec	*Ink per color per page / page print time*
Full black ink coverage	40.2 ml/m²	*Ink drop volume x colors x drops per square metre*
Ejection ink surface tension	38.5 mN/m	*Surface tension required for ejection*
Ink pressure	5.5 kPa	*2 x Ejection ink surface tension / nozzle radius*
Ink column height	545 mm	*Ink column height to achieve ink pressure*

I Claim:

1. A color video printer using a printing head comprising

(a) a plurality of drop-emitter nozzles;

(b) a body of ink associated with said nozzles;

(c) pressure means for subjecting ink in said body of ink to a pressure of at least 2% above ambient pressure, at least during drop selection and separation;

(d) drop selection means for selecting predetermined nozzles and generating a difference in meniscus position between ink in selected and non-selected nozzles; and

(e) drop separating means for causing ink from selected nozzles to separate as drops from the body of ink, while allowing ink to be retained in non-selected nozzles.

2. A color video printer using a printing head comprising

(a) a plurality of drop-emitter nozzles;

(b) a body of ink associated with said nozzles;

(c) drop selection means for selecting predetermined nozzles and generating a difference in meniscus position between ink in selected and non-selected nozzles; and

(d) drop separating means for causing ink from selected nozzles to separate as drops from the body of ink, while allowing ink to be retained in non-selected nozzles, said drop selecting means being capable of producing said difference in miniscus position in the absence of said drop separation means.

3. A color video printer using a printing head comprising

(a) a plurality of drop-emitter nozzles;

(b) a body of ink associated with said nozzles, said ink exhibiting a surface tension decrease of at least 10 mN/m over a 30°C temperature range;

(c) drop selection means for selecting predetermined nozzles and generating a difference in meniscus position between ink in selected and non-selected nozzles; and

(d) drop separating means for causing ink from selected nozzles to separate as drops from the body of ink, while allowing ink to be retained in non-selected nozzles.

4. A color video printing apparatus including:

(a) a video input format conversion process;

(b) a digital frame store;

(c) a digital halftoning unit which converts the continuous tone image data stored in said digital frame store to bi-level image data;

(d) a data distribution and timing system which provides the bi-level image data to the printing head at the correct time during a printing operation; and

(e) a bi-level color printing mechanism including a printer having a print head comprising:

(1) a plurality of drop-emitter nozzles;

(2) a body of ink associated with said nozzles;

(3) pressure means for subjecting ink in said body of ink to a pressure of at least 2% above ambient pressure, at least during drop selection and separation;

(4) drop selection means for selecting predetermined nozzles and generating a difference in meniscus position between ink in selected and non-selected nozzles; and

(5) drop separating means for causing ink from selected nozzles to separate as drops from the body of ink, while allowing ink to be retained in non-selected nozzles.

5. A color video printing apparatus as claimed in claim 4 where the bi-level printing mechanism is a single monolithic concurrent drop selection and drop separation printing head which can print to the full width of the photographic print.

6. A color video printing apparatus as claimed in claim 4 where the bi-level printing mechanism is composed of a plurality of monolithic concurrent drop selection and drop separation printing heads.

7. A color video printing apparatus as claimed in claim 4 where the print paper is in the form of pre-cut sheets.

8. A color video printing apparatus as claimed in claim 4 where the print paper is in the form of a continuous roll, and which incorporates an automatic paper cutter.

9. A color video printing apparatus including:

(a) a video input format conversion process;

(b) a digital frame store;

(c) a digital halftoning unit which converts the continuous tone image data stored in said digital frame store to bi-level image data;

(d) a data distribution and timing system which provides the bi-level image data to the printing head at the correct time during a printing operation; and

(e) a bi-level color printing mechanism including a printer having a print head comprising:

(1) a plurality of drop-emitter nozzles;

(2) a body of ink associated with said nozzles;

(3) drop selection means for selecting predetermined nozzles and generating a difference in meniscus position between ink in selected and non-selected nozzles; and

(4) drop separating means for causing ink from selected nozzles to separate as drops from the body of ink, while allowing ink to be retained in non-selected nozzles, said drop selecting means being capable of producing said difference in miniscus position in the absence of said drop separation means.

10. A color video printing apparatus as claimed in claim 9 where the bi-level printing mechanism is a single monolithic concurrent drop

selection and drop separation printing head which can print to the full width of the photographic print.

11. A color video printing apparatus as claimed in claim 9 where the bi-level printing mechanism is composed of a plurality of monolithic concurrent drop selection and drop separation printing heads.

12. A color video printing apparatus as claimed in claim 9 where the print paper is in the form of pre-cut sheets.

13. A color video printing apparatus as claimed in claim 9 where the print paper is in the form of a continuous roll, and which incorporates an automatic paper cutter.

14. A color video printing apparatus including:

(a) a video input format conversion process;

(b) a digital frame store;

(c) a digital halftoning unit which converts the continuous tone image data stored in said digital frame store to bi-level image data;

(d) a data distribution and timing system which provides the bi-level image data to the printing head at the correct time during a printing operation; and

(e) a bi-level color printing mechanism including a printer having a print head comprising:

(1) a plurality of drop-emitter nozzles;

(2) a body of ink associated with said nozzles, said ink exhibiting a surface tension decrease of at least 10 mN/m over a 30°C temperature range;

(3) drop selection means for selecting predetermined nozzles and generating a difference in meniscus position between ink in selected and non-selected nozzles; and

(4) drop separating means for causing ink from selected nozzles to separate as drops from the body of ink, while allowing ink to be retained in non-selected nozzles.

15. A color video printing apparatus as claimed in claim 14 where the bi-level printing mechanism is a single monolithic concurrent drop selection and drop separation printing head which can print to the full width of the photographic print.

16. A color video printing apparatus as claimed in claim 14 where the bi-level printing mechanism is composed of a plurality of monolithic concurrent drop selection and drop separation printing heads.

17. A color video printing apparatus as claimed in claim 14 where the print paper is in the form of pre-cut sheets.

18. A color video printing apparatus as claimed in claim 14 where the print paper is in the form of a continuous roll, and which incorporates an automatic paper cutter.

19. A PhotoCD player incorporating a printing mechanism using a printing head comprising:

(a) a plurality of drop-emitter nozzles;

(b) a body of ink associated with said nozzles;

(c) pressure means for subjecting ink in said body of ink to a pressure of at least 2% above ambient pressure, at least during drop selection and separation;

(d) drop selection means for selecting predetermined nozzles and generating a difference in meniscus position between ink in selected and non-selected nozzles; and

(e) drop separating means for causing ink from selected nozzles to separate as drops from the body of ink, while allowing ink to be retained in non-selected nozzles.

20. A PhotoCD player incorporating a printing mechanism using a printing head comprising:

(a) a plurality of drop-emitter nozzles;

(b) a body of ink associated with said nozzles;

(c) drop selection means for selecting predetermined nozzles and generating a difference in meniscus position between ink in selected and non-selected nozzles; and

(d) drop separating means for causing ink from selected nozzles to separate as drops from the body of ink, while allowing ink to be retained in non-selected nozzles, said drop selecting means being capable of producing said difference in miniscus position in the absence of said drop separation means.

21. A PhotoCD player incorporating a printing mechanism using a printing head comprising:

(a) a plurality of drop-emitter nozzles;

(b) a body of ink associated with said nozzles, said ink exhibiting a surface tension decrease of at least 10 mN/m over a 30°C temperature range;

(c) drop selection means for selecting predetermined nozzles and generating a difference in meniscus position between ink in selected and non-selected nozzles; and

(d) drop separating means for causing ink from selected nozzles to separate as drops from the body of ink, while allowing ink to be retained in non-selected nozzles.

22. A PhotoCD player incorporating a printing apparatus including:

(a) a computing element;

(b) digital data storage system;

(c) a CD-ROM drive;

(d) an image decompression system;

(e) a digital halftoning system;

(f) a bi-level image memory;

(g) a data distribution and timing system which provides the bi-level image data to the printing head at the correct time during a printing operation; and

(h) a bi-level printing mechanism including a printer having a print head comprising:

(1) a plurality of drop-emitter nozzles;

(2) a body of ink associated with said nozzles;

(3) pressure means for subjecting ink in said body of ink to a pressure of at least 2% above ambient pressure, at least during drop selection and separation;

(4) drop selection means for selecting predetermined nozzles and generating a difference in meniscus position between ink in selected and non-selected nozzles; and

(5) drop separating means for causing ink from selected nozzles to separate as drops from the body of ink, while allowing ink to be retained in non-selected nozzles.

23. A PhotoCD player incorporating a printing apparatus including:

(a) a computing element;

(b) digital data storage system;

(c) a CD-ROM drive;

(d) an image decompression system;

(e) a digital halftoning system;

(f) a bi-level image memory;

(g) a data distribution and timing system which provides the bi-level image data to the printing head at the correct time during a printing operation; and

(h) a bi-level printing mechanism including a printer having a print head comprising:

(1) a plurality of drop-emitter nozzles;

(2) a body of ink associated with said nozzles;

(3) drop selection means for selecting predetermined nozzles and generating a difference in meniscus position between ink in selected and non-selected nozzles; and

(4) drop separating means for causing ink from selected nozzles to separate as drops from the body of ink, while allowing ink to be retained in non-selected nozzles, said drop selecting means being capable of producing said difference in miniscus position in the absence of said drop separation means.

24. A PhotoCD player incorporating a printing apparatus including:

(a) a computing element;

(b) digital data storage system;

(c) a CD-ROM drive;

(d) an image decompression system;

(e) a digital halftoning system;

(f) a bi-level image memory;

(g) a data distribution and timing system which provides the bi-level image data to the printing head at the correct time during a printing operation; and

(h) a bi-level printing mechanism including a printer having a print head comprising:

(1) a plurality of drop-emitter nozzles;

(2) a body of ink associated with said nozzles, said ink exhibiting a surface tension decrease of at least 10 mN/m over a 30°C temperature range;

(3) drop selection means for selecting predetermined nozzles and generating a difference in meniscus position between ink in selected and non-selected nozzles; and

(4) drop separating means for causing ink from selected nozzles to separate as drops from the body of ink, while allowing ink to be retained in non-selected nozzles.

25. A color video printer substantially as herein described, with reference to the accompanying diagrams.

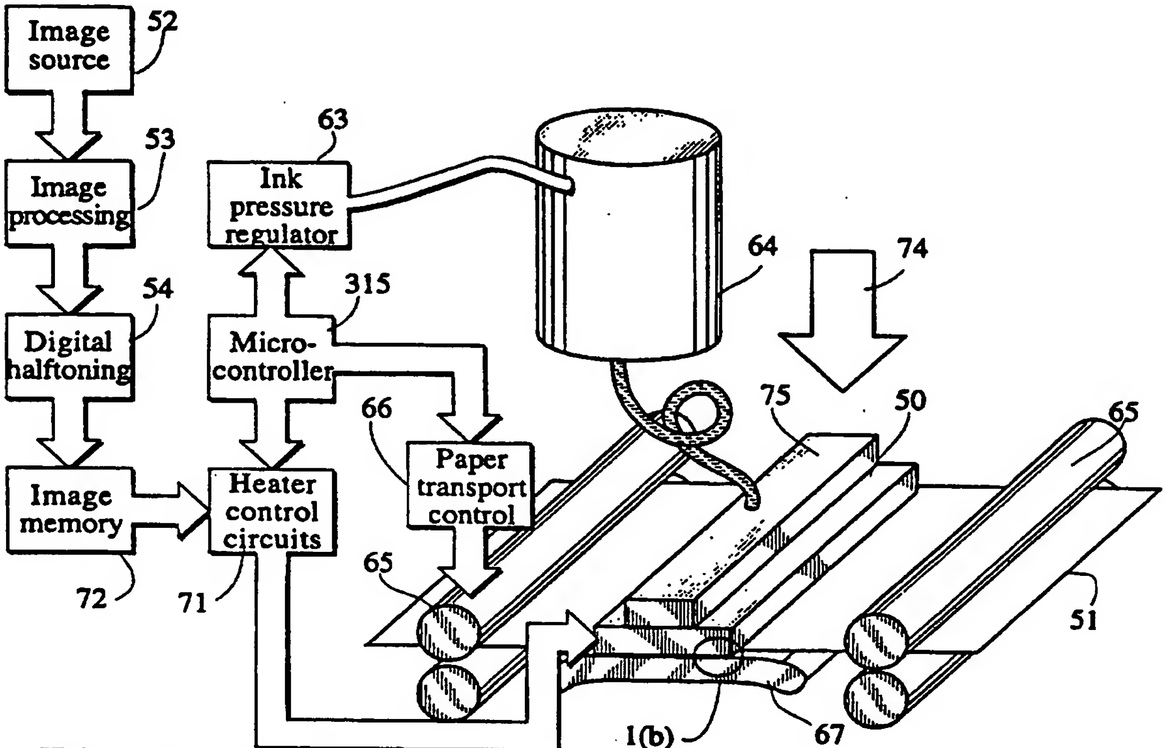


Image source
52
Image processing
53
Digital halftoning
54
Image memory
72
Ink pressure regulator
63
315
Micro-controller
Heater control circuits
71
66
Paper transport control
64
74
75
50
65
51
65
1(b)
67

Fig. 1(a)

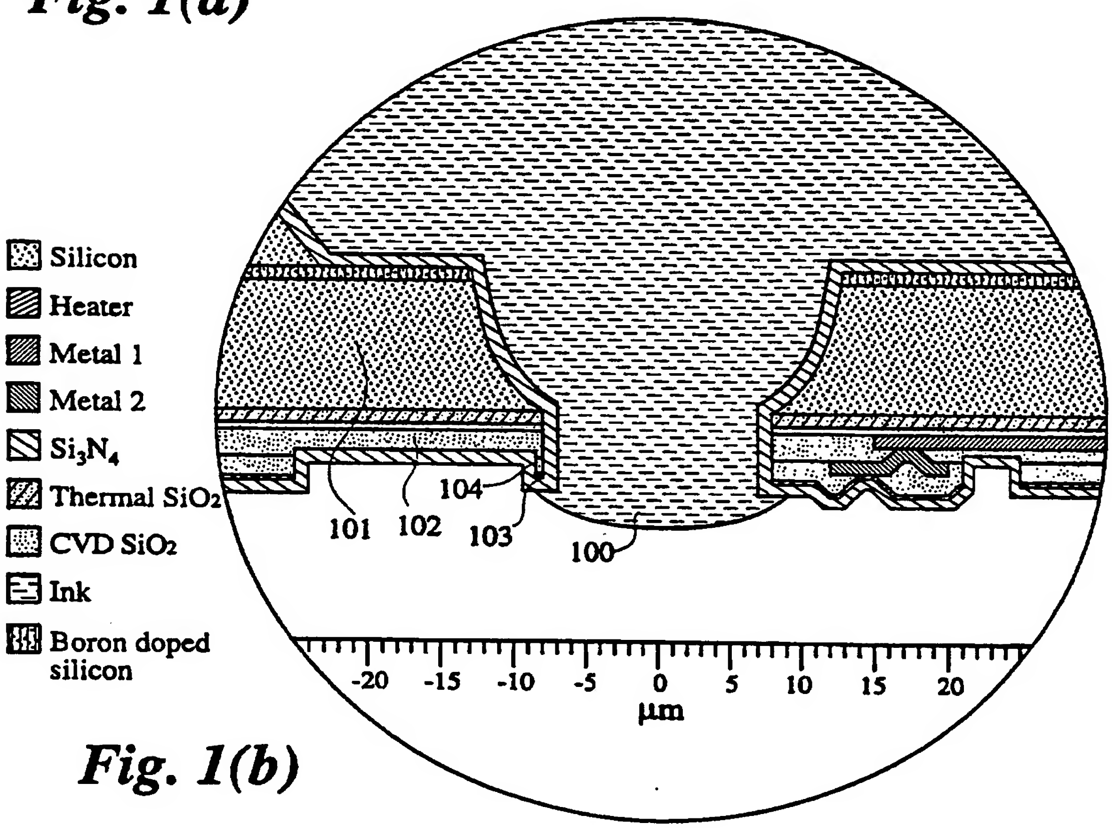

Silicon
Heater
Metal 1
Metal 2
Si3N4
Thermal SiO2
CVD SiO2
Ink
Boron doped silicon
101
102
104
103
100
-20
-15
-10
-5
0
5
10
15
20
µm

Fig. 1(b)

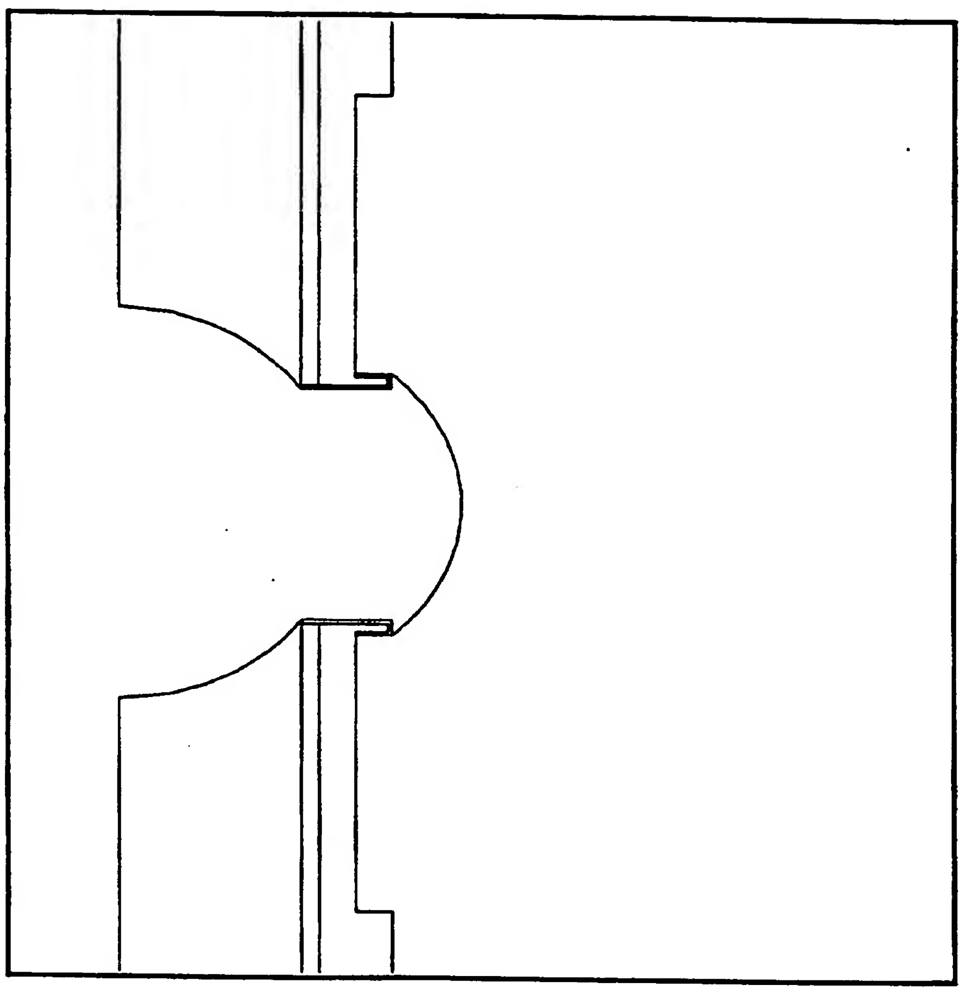


Fig. 2(a)

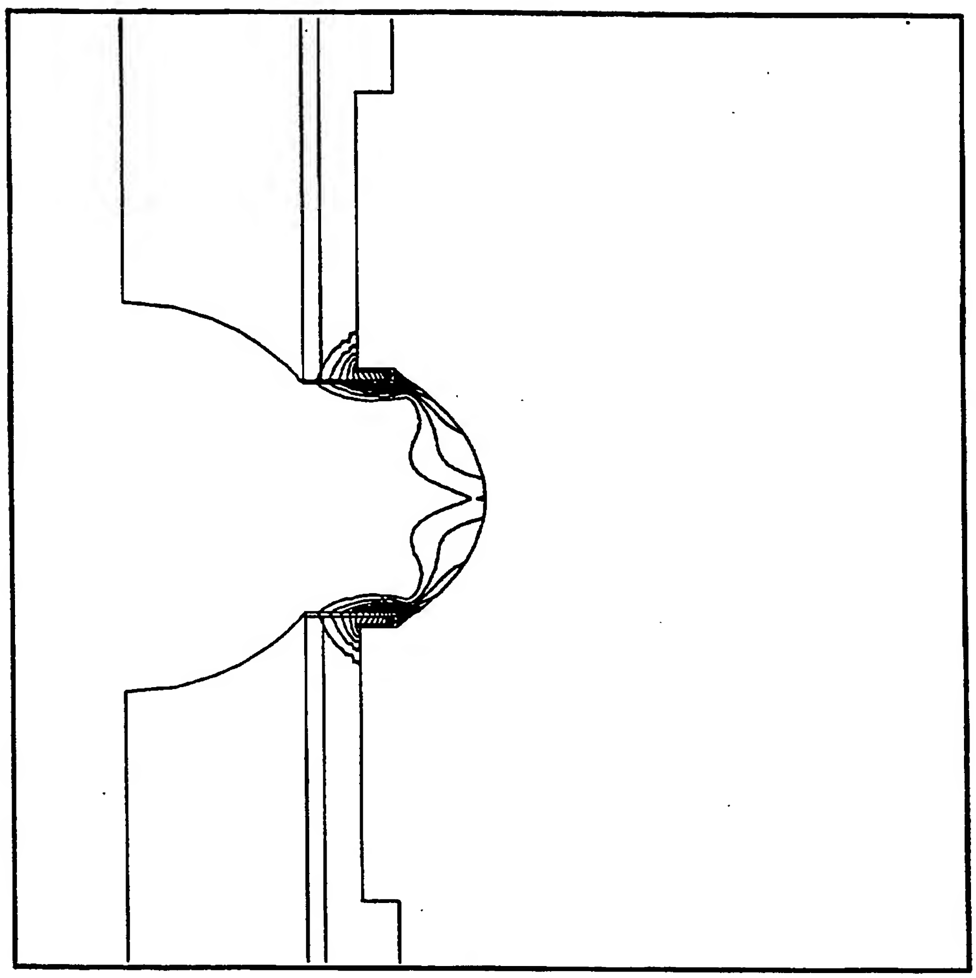


Fig. 2(b)

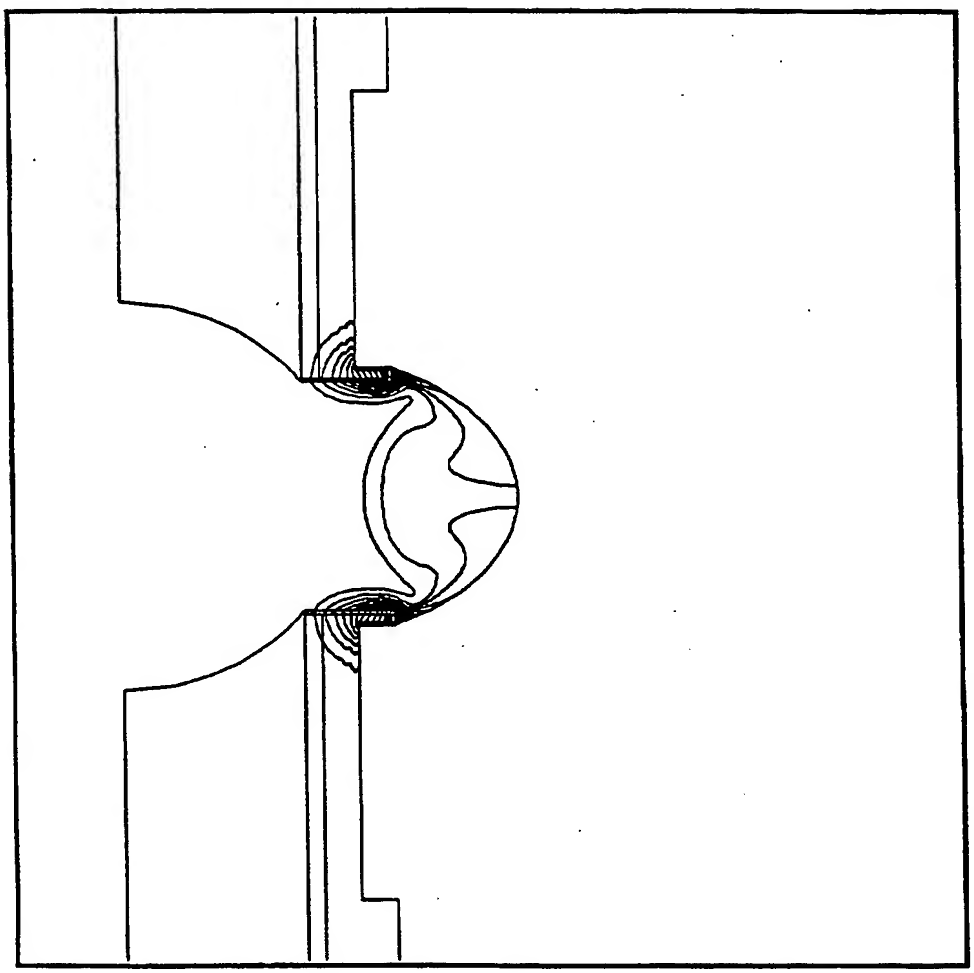


Fig. 2(c)

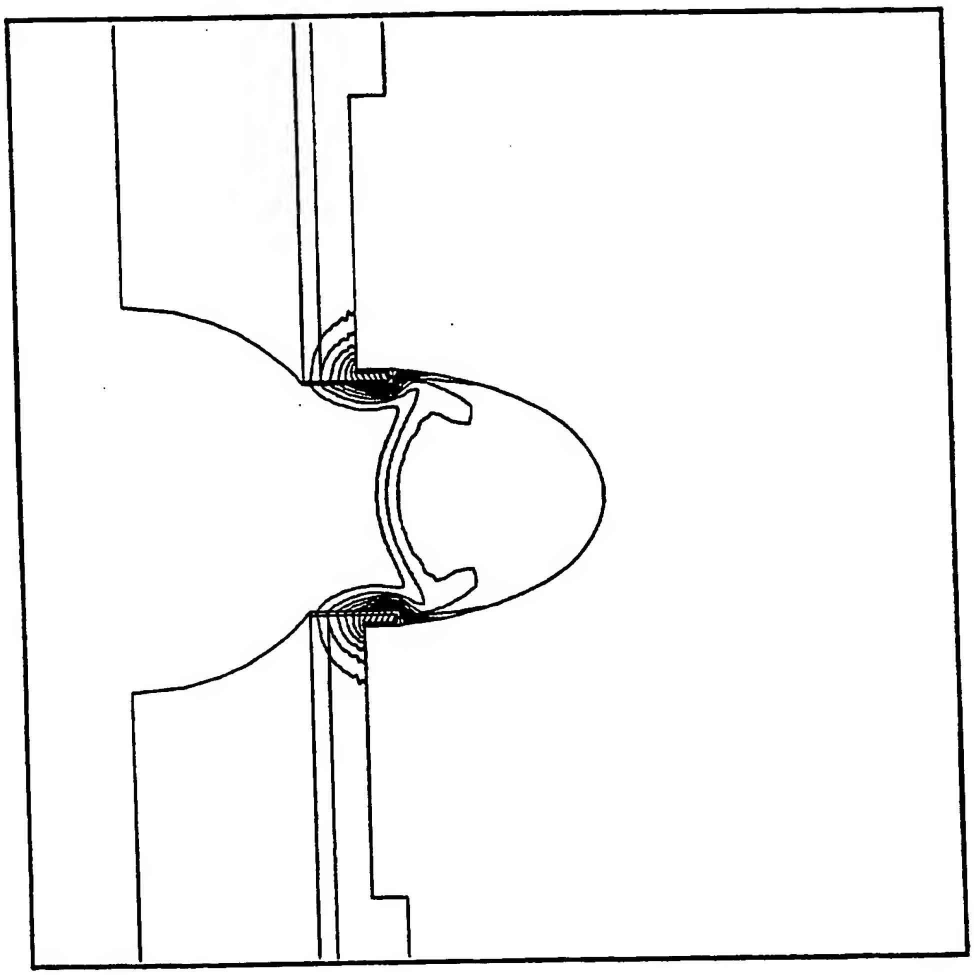


Fig. 2(d)

SUBSTITUTE SHEET (RULE 26)

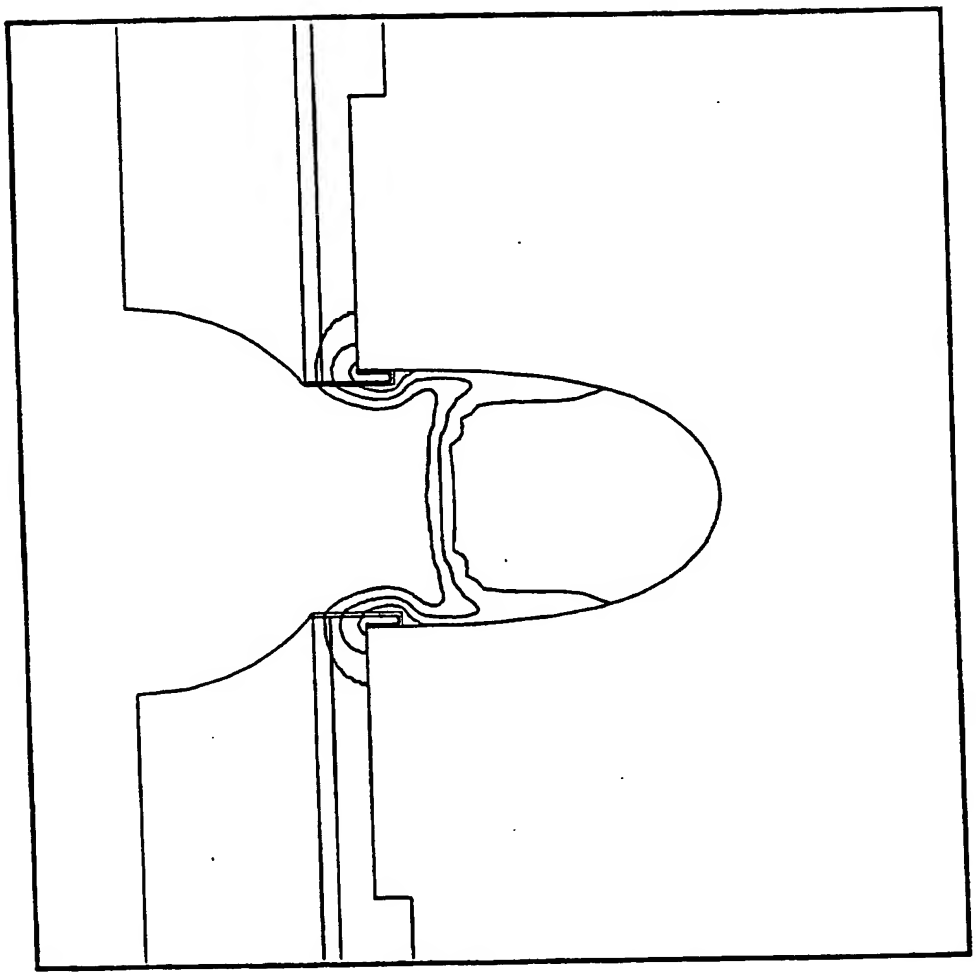


Fig. 2(e)

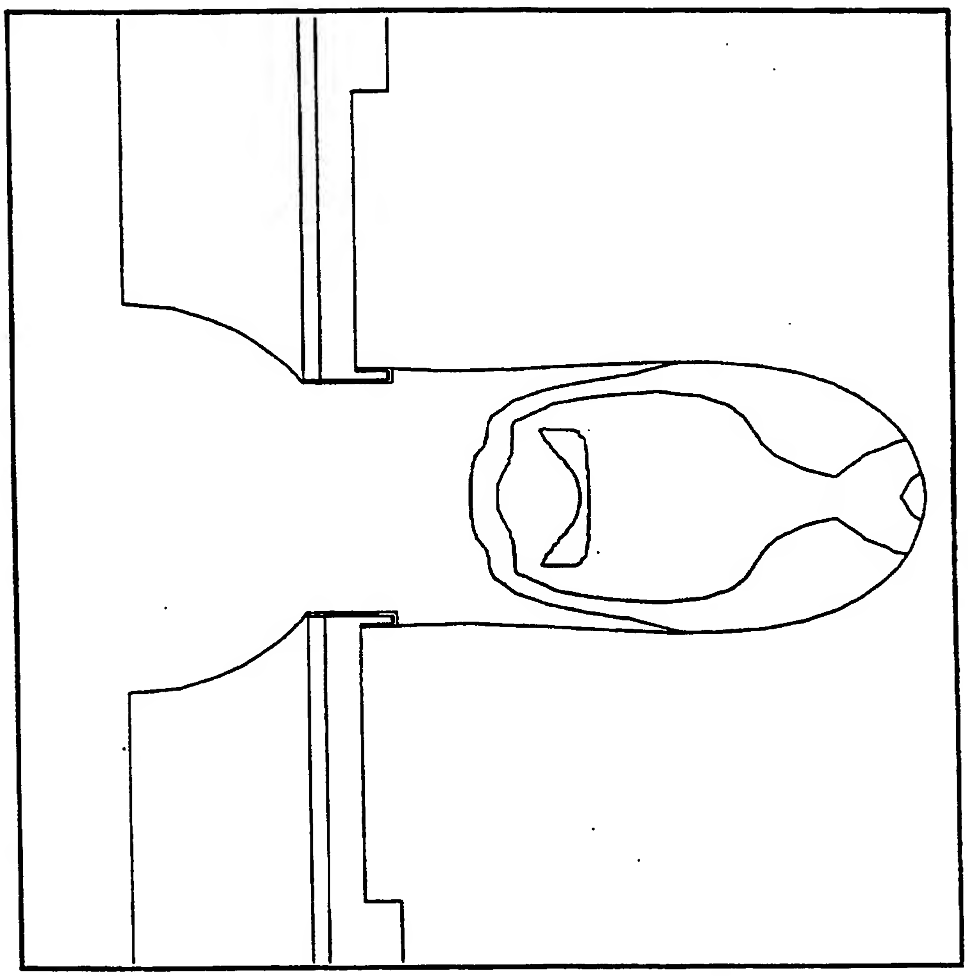


Fig. 2(f)

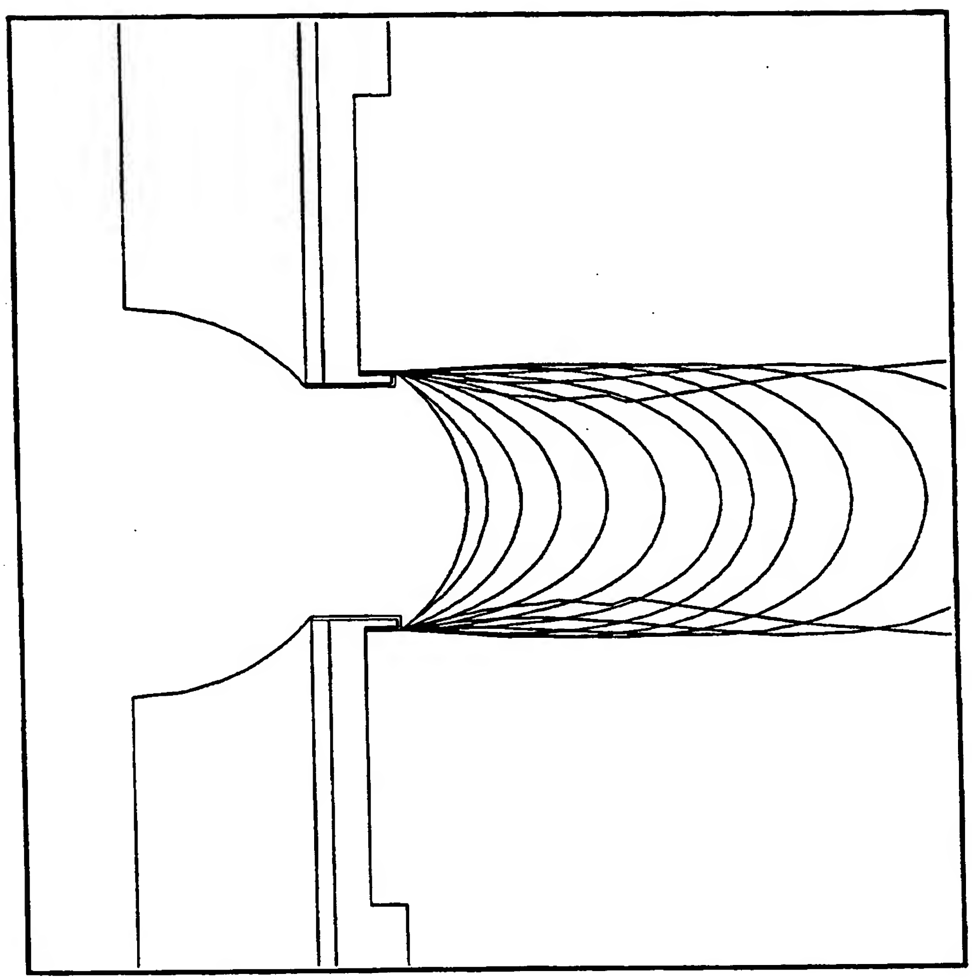


Fig. 3(a)

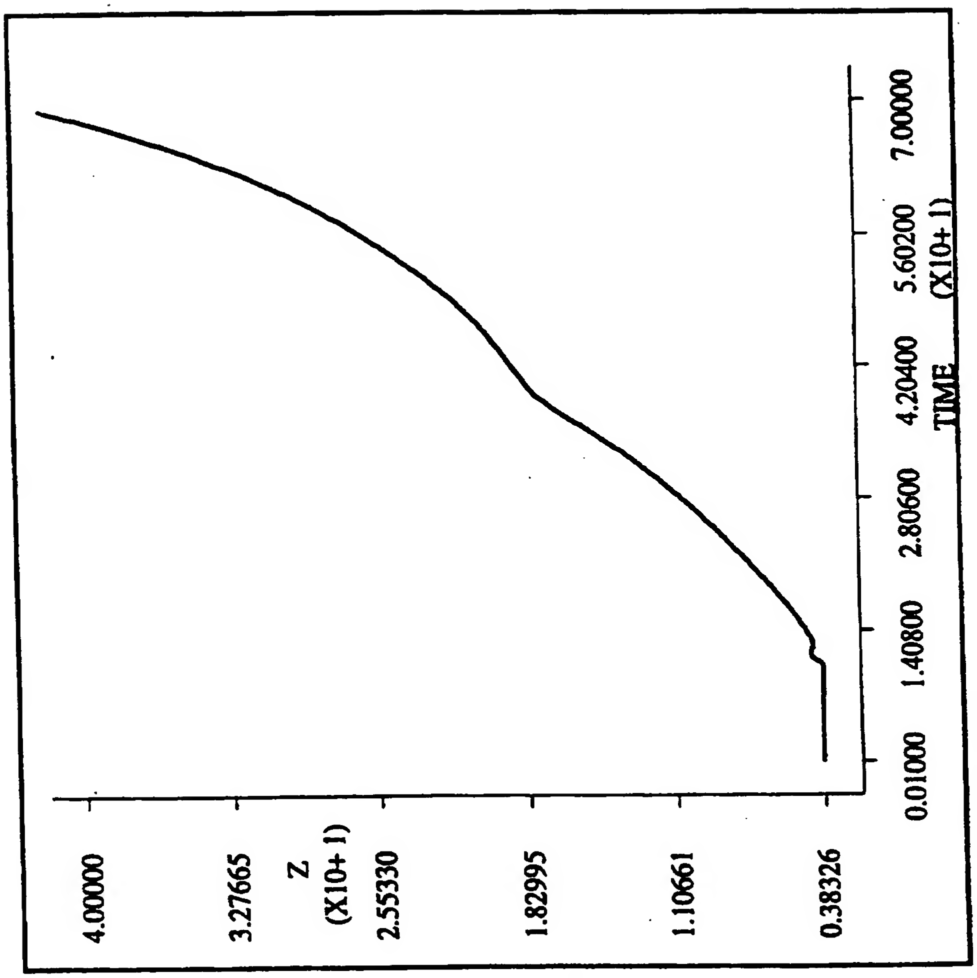

4.00000
3.27665
Z
(X10+ 1)
2.55330
1.82995
1.10661
0.38326
0.01000
1.40800
2.80600
4.20400
5.60200
7.00000
TIME
(X10+ 1)

Fig.3(b)

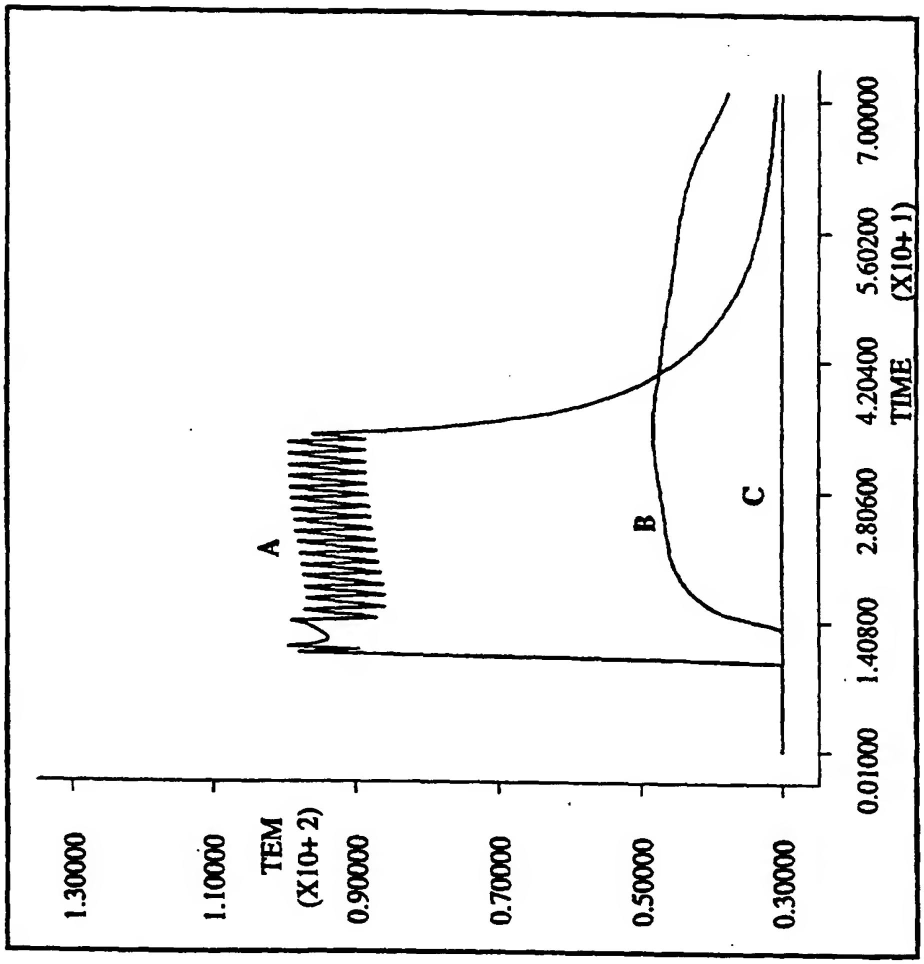

TEM
(X10+ 2)
1.30000
1.10000
0.90000
0.70000
0.50000
0.30000
A
B
C
0.01000
1.40800
2.80600
4.20400
5.60200
7.00000
TIME
(X10+ 1)

Fig. 3(c)

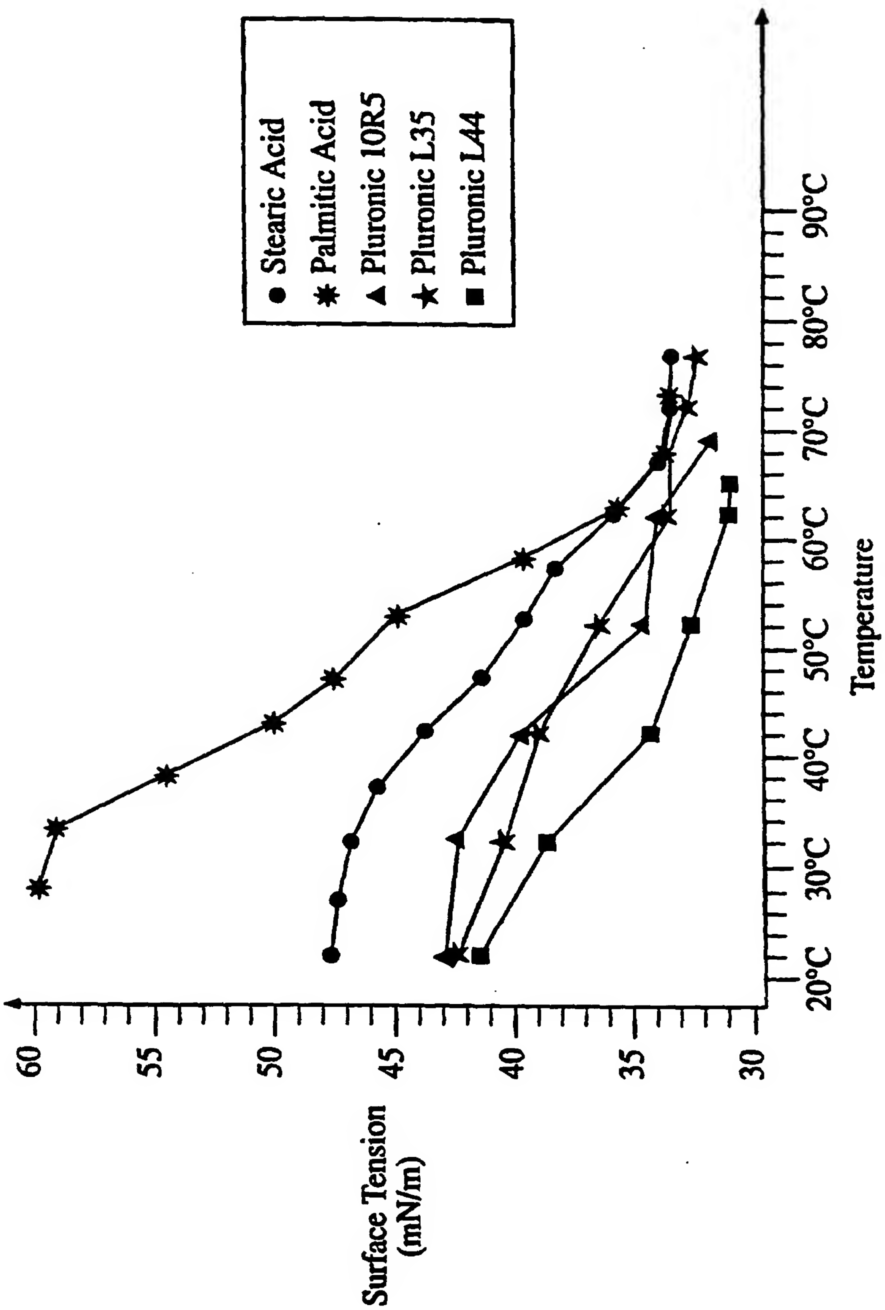

Stearic Acid
Palmitic Acid
Pluronic 10R5
Pluronic L35
Pluronic L44
Surface Tension (mN/m)
60
55
50
45
40
35
30
20°C
30°C
40°C
50°C
60°C
70°C
80°C
90°C
Temperature

Fig. 3(d)

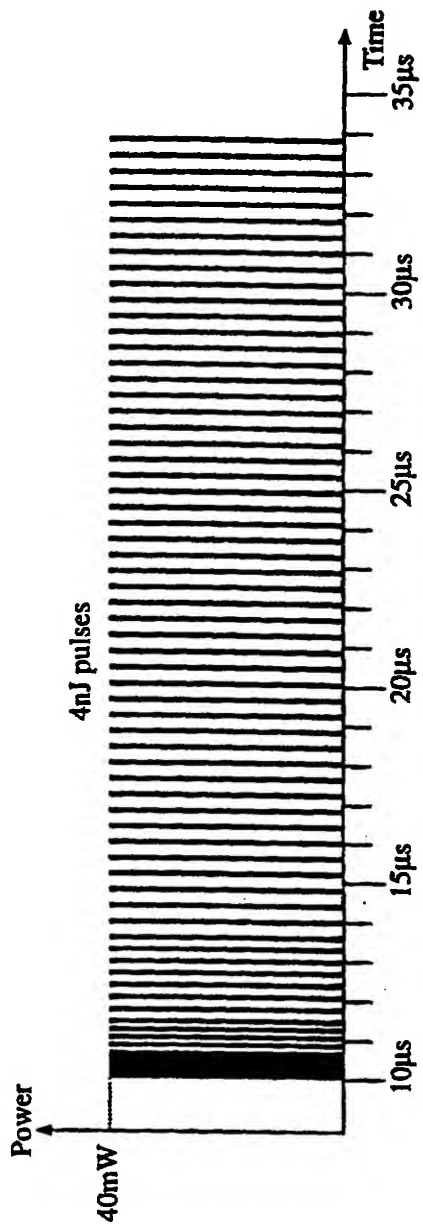


Fig. 3(e)

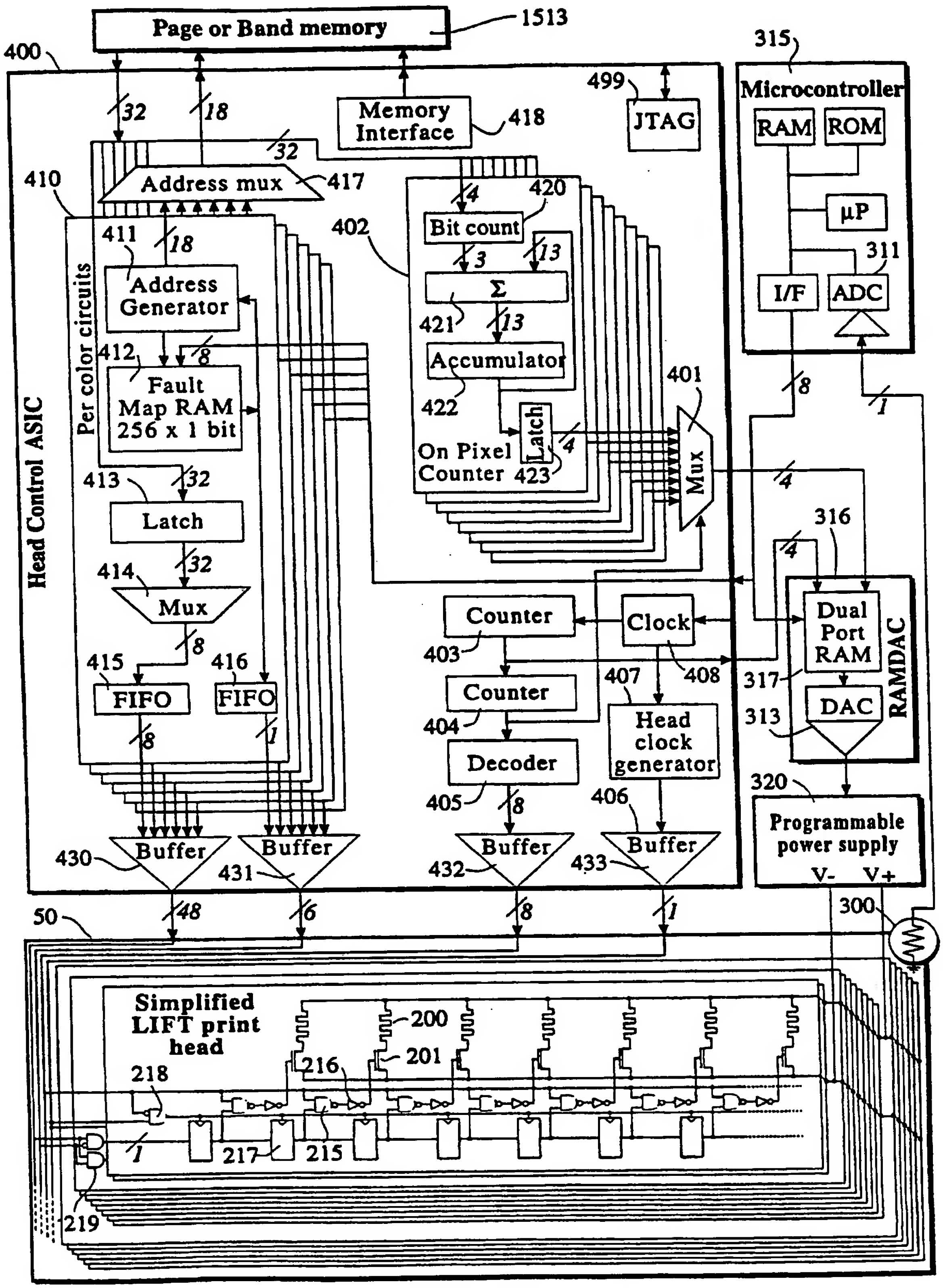

Page or Band memory
1513
400
315
Microcontroller
RAM
ROM
µP
311
I/F
ADC
499
JTAG
Memory Interface
418
32
18
32
Address mux
417
410
411
18
Address Generator
412
8
Fault Map RAM 256 x 1 bit
413
32
Latch
414
32
Mux
8
415
416
FIFO
FIFO
8
1
Per color circuits
Head Control ASIC
402
420
4
Bit count
3
13
Σ
421
13
Accumulator
422
Latch
4
4
On Pixel Counter
423
401
Mux
8
4
316
4
Dual Port RAM
DAC
RAMDAC
317
313
1
Counter
Clock
403
Counter
407
408
404
Decoder
Head clock generator
405
8
406
Buffer
Buffer
Buffer
Buffer
430
431
432
433
320
Programmable power supply
V-
V+
300
50
48
6
8
1
Simplified LIFT print head
200
201
216
218
1
217
215
219

Fig. 4

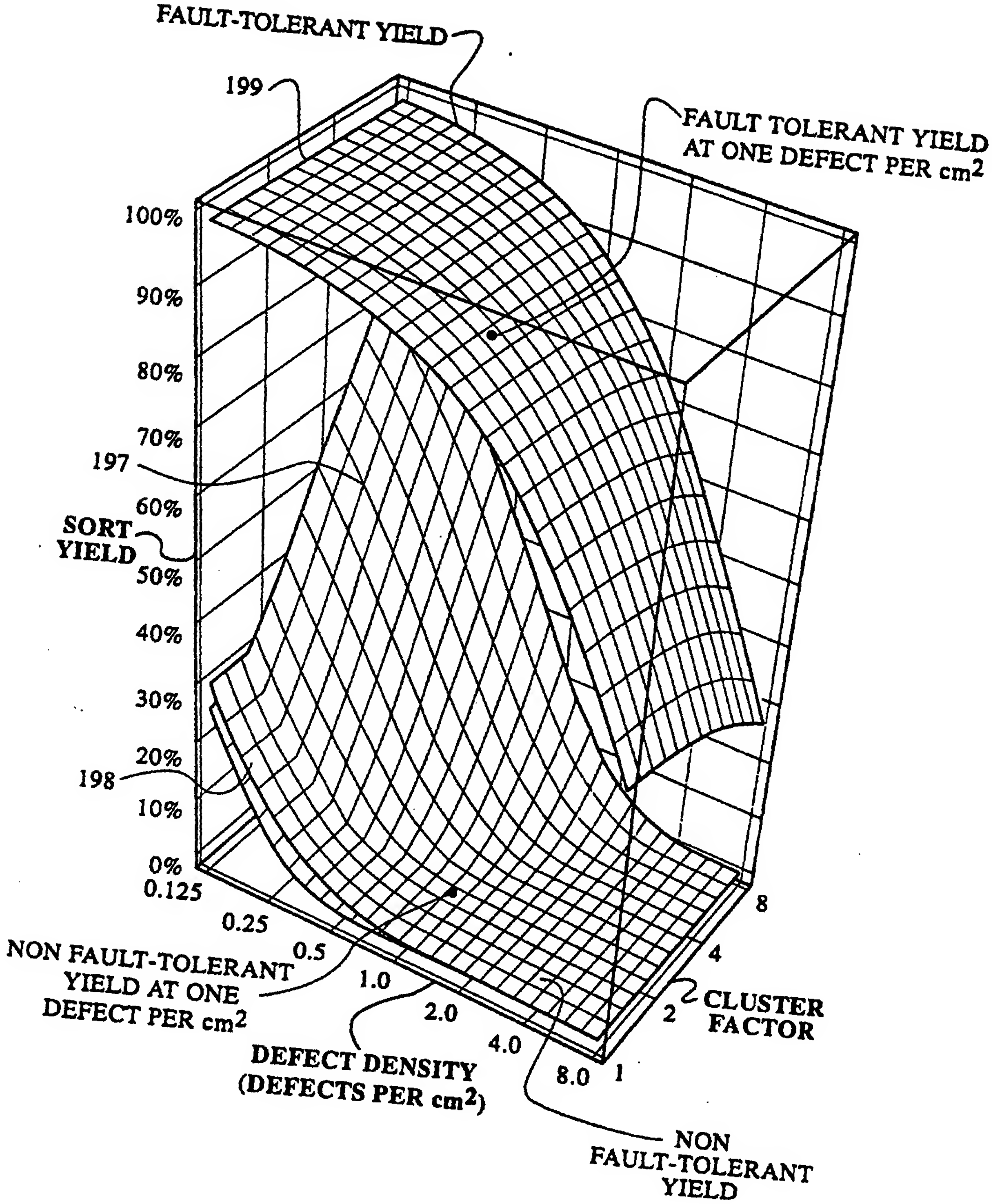

FAULT-TOLERANT YIELD
199
FAULT TOLERANT YIELD AT ONE DEFECT PER cm2
100%
90%
80%
70%
197
60%
SORT YIELD
50%
40%
30%
20%
198
10%
0%
0.125
0.25
0.5
1.0
2.0
4.0
8.0
NON FAULT-TOLERANT YIELD AT ONE DEFECT PER cm2
DEFECT DENSITY (DEFECTS PER cm2)
8
4
2
1
CLUSTER FACTOR
NON FAULT-TOLERANT YIELD

Fig. 5

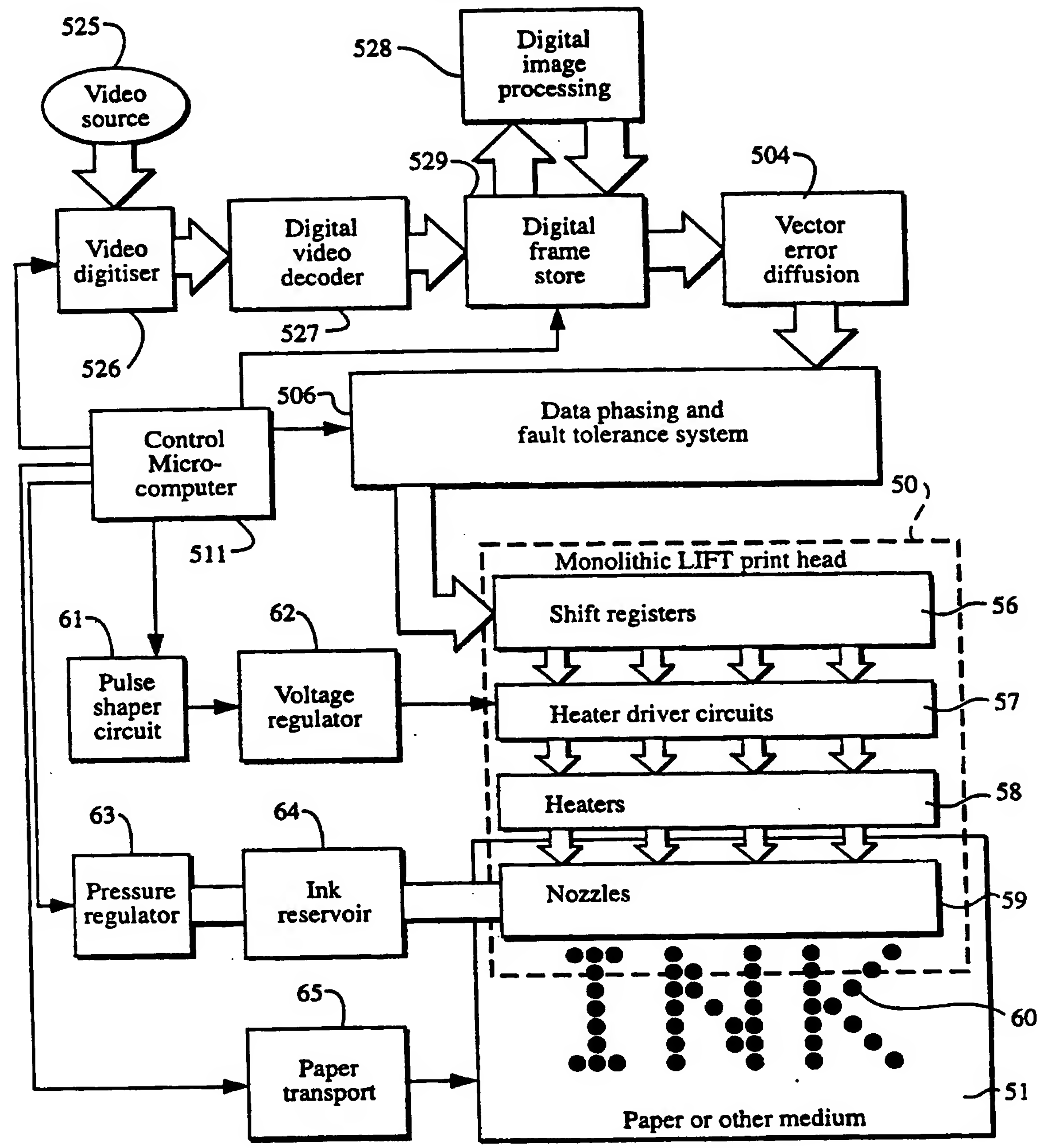

525
Video source
528
Digital image processing
529
504
Video digitiser
Digital video decoder
Digital frame store
Vector error diffusion
526
527
506
Data phasing and fault tolerance system
Control Micro-computer
511
50
Monolithic LIFT print head
Shift registers
56
61
62
Pulse shaper circuit
Voltage regulator
Heater driver circuits
57
Heaters
58
63
64
Pressure regulator
Ink reservoir
Nozzles
59
60
65
Paper transport
51
Paper or other medium

Fig. 6(a)

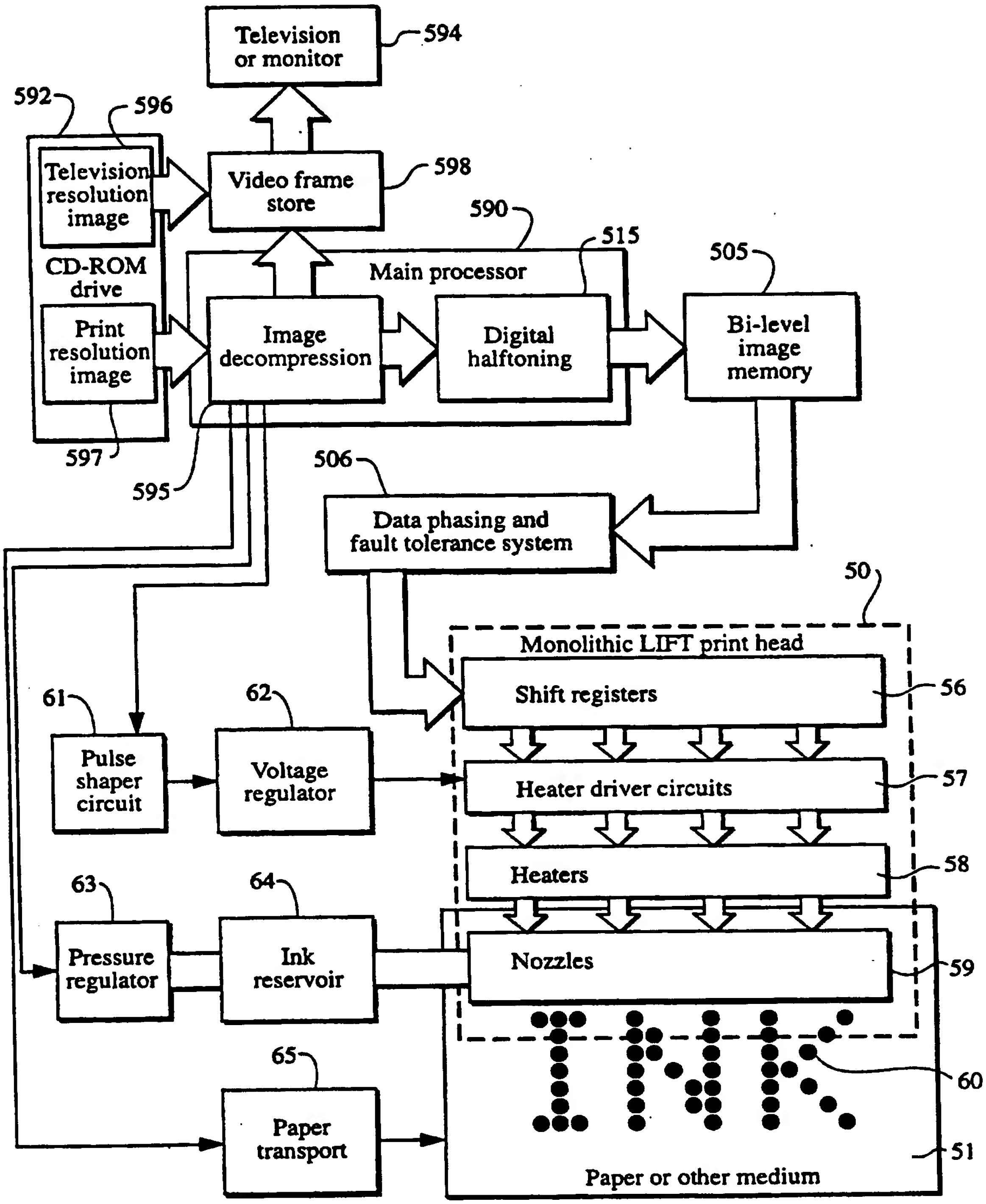

Television or monitor
594
592
596
Television resolution image
Video frame store
598
590
CD-ROM drive
515
505
Main processor
Print resolution image
Image decompression
Digital halftoning
Bi-level image memory
597
595
506
Data phasing and fault tolerance system
50
Monolithic LIFT print head
Shift registers
56
61
62
Pulse shaper circuit
Voltage regulator
Heater driver circuits
57
Heaters
58
63
64
Pressure regulator
Ink reservoir
Nozzles
59
60
65
Paper transport
51
Paper or other medium

Fig. 6(b)

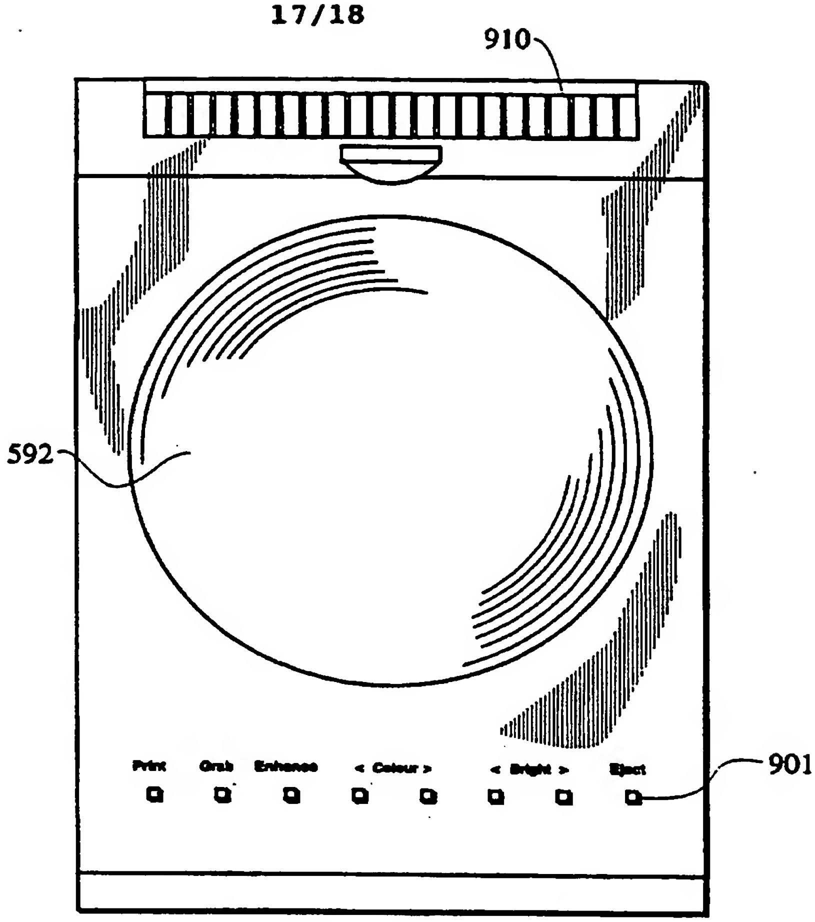

910
592
Print
Grab
Enhance
< Colour >
< Bright >
Eject
901

Fig. 7(a)

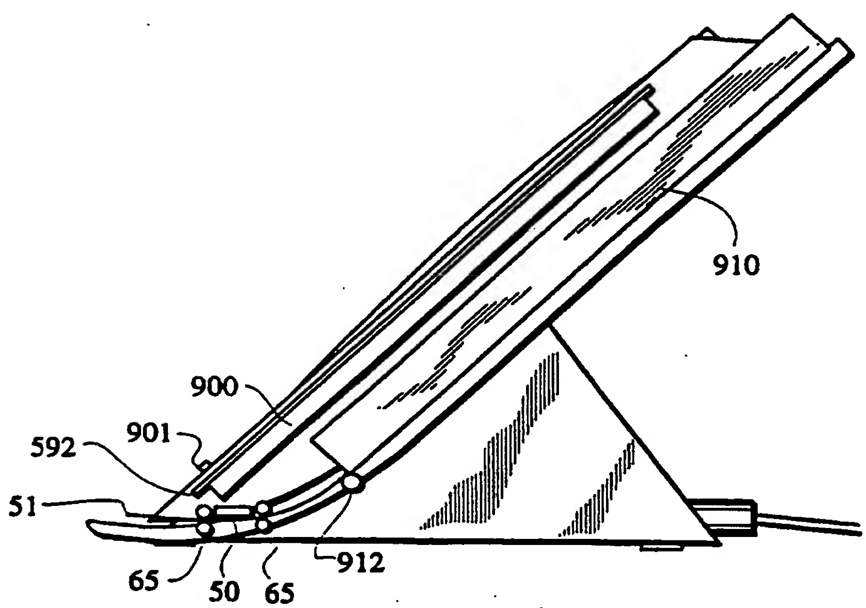

910
900
901
592
51
912
65
50
65

Fig. 7(b)

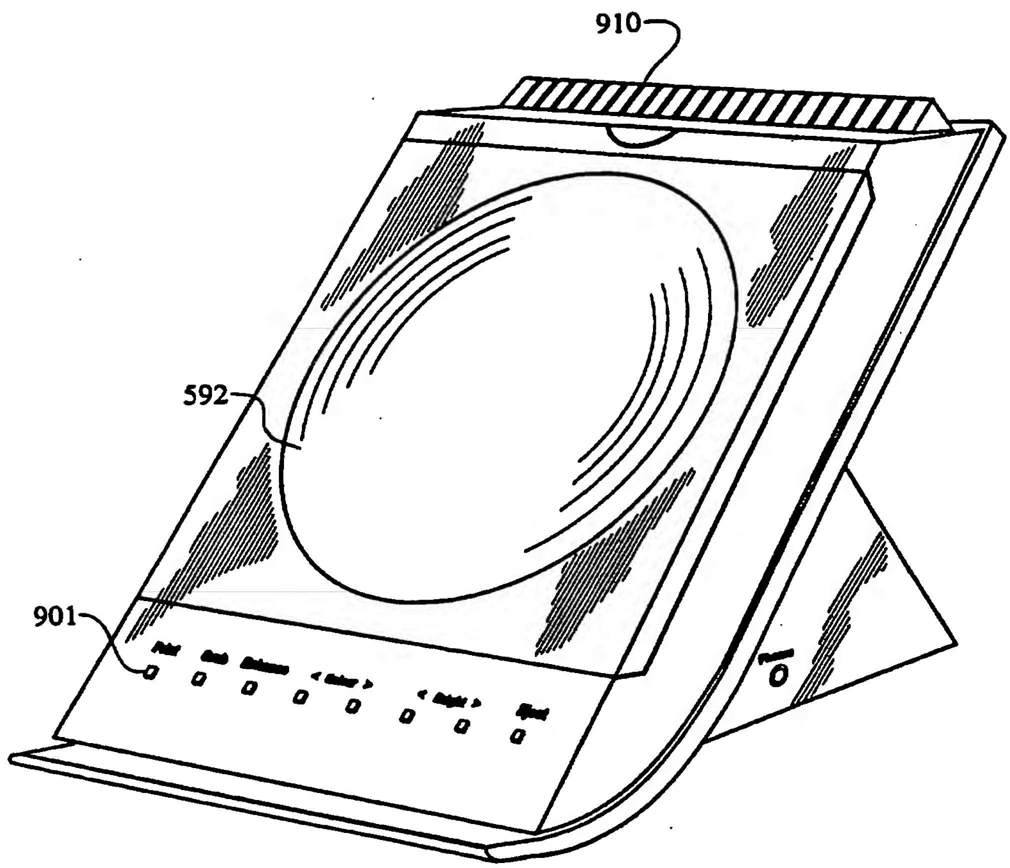


Fig. 8

INTERNATIONAL SEARCH REPORT

Inter nal Application No
PCT/US 96/04907

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B41J2/04 H04N1/23

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B41J H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A,4 758 885 (SASAKI ET AL.) 19 July 1988 see the whole document ---	1-24
Y	COMPUTER TECHNOLOGY REVIEW, vol. 11, no. 14, 1 October 1991, pages 53-54, 56, XP000275142 STEPNES S S: "PHOTO CD TECHNOLOGY MAKES 35 MM CAMERAS COMPUTER PERIPHERALS" see page 53 - page 56 ---	1-24
Y	WO,A,92 05657 (N.V. PHILIPS' GLOEILAMPEMFABRIEKEN) 2 April 1992 see the whole document ---	19-24
Y	EP,A,0 600 712 (HEWLETT-PACKARD COMPANY) 8 June 1994 see the whole document ---	1-24
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
13 August 1996	29.08.96

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Meulemans, J-P

Inter nal Application No
PCT/US 96/04907

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

	Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Y	US,A,4 312 009 (LANGE) 19 January 1982 see the whole document ---	1-24
	Y	WO,A,90 14233 (P.A. CONSULTING SERVICES LIMITED) 29 November 1990 see the whole document ---	1-23
	Y	US,A,4 293 865 (JINNAI ET AL.) 6 October 1981 see the whole document ---	1-23
	Y	US,A,4 752 783 (SAITO ET AL.) 21 June 1988 see the whole document ---	1-23
	Y	PATENT ABSTRACTS OF JAPAN vol. 010, no. 066 (M-461), 15 March 1986 & JP,A,60 210462 (FUJI XEROX KK), 22 October 1985, see abstract ---	1-23
	Y	US,A,4 164 745 (CIELO ET AL.) 14 August 1979 see the whole document ---	1-23
	Y	EP,A,0 498 292 (CANON INFORMATION SYSTEMS AUSTRALIA) 12 August 1992 see page 5, line 9 - line 51 ---	5,6,10, 11,15,16
	Y	US,A,4 764 777 (SAITO ET AL.) 16 August 1988 see the whole document ---	3,14
	A	DE,A,29 49 808 (NIPPON ELECTRIC CO., LTD.) 10 July 1980 see the whole document ---	1,4,22
	A	WO,A,91 12686 (EASTMAN KODAK COMPANY) 22 August 1991 see page 11, line 27 - page 12, line 18 ---	4,9,14, 22-24
	A	WO,A,91 06174 (EASTMAN KODAK COMPANY) 2 May 1991 see page 7, line 18 - line 31 ---	4,9,14, 22-24
	A	US,A,4 507 685 (KAWAMURA) 26 March 1985 see figures 1,5 ---	4,9,14, 22-24
1	A	EP,A,0 612 181 (LINOTYPE-HELL AG) 24 August 1994 see the whole document ---	4,9,14, 22-24
6	A	DE,A,42 37 255 (HITACHI, LTD.) 13 May 1993 see the whole document --- -/--	19,22,23

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 543 414 (EASTMAN KODAK COMPANY) 26 May 1993 see the whole document ---	19,22,23
A	WO,A,92 05657 (N. V. PHILIPS GLOEILAMPENFABRIEKEN) 2 April 1992 see the whole document -----	19,22,23

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 96/04907

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-4758885	19-07-88	JP-B- 5088589	22-12-93
		JP-A- 61288690	18-12-86
		JP-B- 6036548	11-05-94
		JP-A- 61288662	18-12-86
WO-A-9205657	02-04-92	AU-B- 642540	21-10-93
		AU-B- 8635991	15-04-92
		AU-B- 655944	19-01-95
		AU-B- 8636991	15-04-92
		AU-B- 8637391	15-04-92
		AU-B- 8648591	15-04-92
		AU-B- 658152	06-04-95
		AU-B- 8649091	15-04-92
		AU-B- 8656791	15-04-92
		AU-B- 658153	06-04-95
		AU-B- 8657491	15-04-92
		AU-B- 661829	10-08-95
		AU-B- 8667091	15-04-92
		CA-A- 2068869	20-03-92
		CA-A- 2068883	20-03-92
		CA-A- 2091166	20-03-92
		CA-A- 2092692	20-03-92
		CN-A- 1062064	17-06-92
		CN-A- 1064186	02-09-92
		CN-A,B 1062065	17-06-92
		CN-A- 1067545	30-12-92
		CN-A,B 1061688	03-06-92
		CN-A- 1062066	17-06-92
		EP-A- 0500913	02-09-92
		EP-A- 0506902	07-10-92
		EP-A- 0500927	02-09-92
		HU-A- 64659	28-01-94
		JP-T- 5502539	28-04-93
		JP-T- 5502568	28-04-93
		JP-T- 5502541	28-04-93
		JP-T- 6501362	10-02-94
		JP-T- 8502840	26-03-96
		JP-T- 6501363	10-02-94
		NL-A- 9002108	16-04-92
		NL-A- 9002109	16-04-92

Inte onal Application No
PCT/US 96/04907

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO-A-9205657		NL-A- 9002110	16-04-92
		NL-A- 9002111	16-04-92
		NL-A- 9002112	16-04-92
		NL-A- 9002113	16-04-92
		NL-A- 9002114	16-04-92
		WO-A- 9205651	02-04-92
		WO-A- 9205652	02-04-92
		WO-A- 9205553	02-04-92
		WO-A- 9205653	02-04-92
		WO-A- 9205554	02-04-92
		WO-A- 9205556	02-04-92
		WO-A- 9205658	02-04-92
		SK-A- 143592	09-11-94
		SK-A- 145092	05-10-94
EP-A-600712	08-06-94	US-A- 5381166	10-01-95
		US-A- 5481280	02-01-96
		JP-A- 6293140	21-10-94
US-A-4312009	19-01-82	FR-A- 2448979	12-09-80
		AT-T- 3833	15-07-83
		EP-A- 0014918	03-09-80
WO-A-9014233	29-11-90	NONE	
US-A-4293865	06-10-81	JP-C- 1209308	29-05-84
		JP-A- 55049270	09-04-80
		JP-B- 58040512	06-09-83
US-A-4752783	21-06-88	JP-B- 7064065	12-07-95
		JP-A- 62225388	03-10-87
		JP-B- 7017062	01-03-95
		JP-A- 62225353	03-10-87
US-A-4164745	14-08-79	NONE	
EP-A-498292	12-08-92	AU-B- 8999891	06-08-92
		JP-A- 5338178	21-12-93
		AT-T- 136500	15-04-96
		AU-B- 8999691	06-08-92

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-498292		AU-B- 657720	23-03-95
		AU-B- 9000191	06-08-92
		DE-D- 69209684	15-05-96
		EP-A- 0498291	12-08-92
		EP-A- 0498293	12-08-92
		JP-A- 6040037	15-02-94
		JP-A- 5338171	21-12-93
		JP-A- 5338172	21-12-93
		AU-B- 657929	30-03-95
		AU-B- 667295	21-03-96
US-A-4764777	16-08-88	JP-A- 62225358	03-10-87
DE-A-2949808	10-07-80	JP-A- 55079175	14-06-80
WO-A-9112686	22-08-91	DE-D- 69113254	26-10-95
		DE-T- 69113254	02-05-96
		EP-A- 0514478	25-11-92
		JP-T- 5504035	24-06-93
		US-A- 5214517	25-05-93
WO-A-9106174	02-05-91	US-A- 5070413	03-12-91
		DE-D- 69015205	26-01-95
		DE-T- 69015205	29-06-95
		EP-A- 0495914	29-07-92
		JP-T- 5501341	11-03-93
US-A-4507685	26-03-85	NONE	
EP-A-612181	24-08-94	DE-A- 4331644	25-08-94
		JP-A- 6253162	09-09-94
DE-A-4237255	13-05-93	JP-A- 5128221	25-05-93
		FR-A- 2683347	07-05-93
EP-A-543414	26-05-93	JP-A- 7013971	17-01-95
		US-A- 5414811	09-05-95
WO-A-9205657	02-04-92	AU-B- 642540	21-10-93
		AU-B- 8635991	15-04-92

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 96/04907

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
WO-A-9205657		AU-B-	655944	19-01-95
		AU-B-	8636991	15-04-92
		AU-B-	8637391	15-04-92
		AU-B-	8648591	15-04-92
		AU-B-	658152	06-04-95
		AU-B-	8649091	15-04-92
		AU-B-	8656791	15-04-92
		AU-B-	658153	06-04-95
		AU-B-	8657491	15-04-92
		AU-B-	661829	10-08-95
		AU-B-	8667091	15-04-92
		CA-A-	2068869	20-03-92
		CA-A-	2068883	20-03-92
		CA-A-	2091166	20-03-92
		CA-A-	2092692	20-03-92
		CN-A-	1062064	17-06-92
		CN-A-	1064186	02-09-92
		CN-A,B	1062065	17-06-92
		CN-A-	1067545	30-12-92
		CN-A,B	1061688	03-06-92
		CN-A-	1062066	17-06-92
		EP-A-	0500913	02-09-92
		EP-A-	0506902	07-10-92
		EP-A-	0500927	02-09-92
		HU-A-	64659	28-01-94
		JP-T-	5502539	28-04-93
		JP-T-	5502568	28-04-93
		JP-T-	5502541	28-04-93
		JP-T-	6501362	10-02-94
		JP-T-	8502840	26-03-96
		JP-T-	6501363	10-02-94
		NL-A-	9002108	16-04-92
		NL-A-	9002109	16-04-92
		NL-A-	9002110	16-04-92
		NL-A-	9002111	16-04-92
		NL-A-	9002112	16-04-92
		NL-A-	9002113	16-04-92
		NL-A-	9002114	16-04-92
		WO-A-	9205651	02-04-92
		WO-A-	9205652	02-04-92

INTERNATIONAL SEARCH REPORT

Information on patent family members

Intr ional Application No
PCT/US 96/04907

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO-A-9205657		WO-A- 9205553	02-04-92
		WO-A- 9205653	02-04-92
		WO-A- 9205554	02-04-92
		WO-A- 9205556	02-04-92
		WO-A- 9205658	02-04-92
		SK-A- 143592	09-11-94
		SK-A- 145092	05-10-94

Form PCT/ISA/210 (patent family annex) (July 1992)

EUROPEAN PATENT OFFICE

Patent Abstracts of Japan

PUBLICATION NUMBER : 09116843
PUBLICATION DATE : 02-05-97

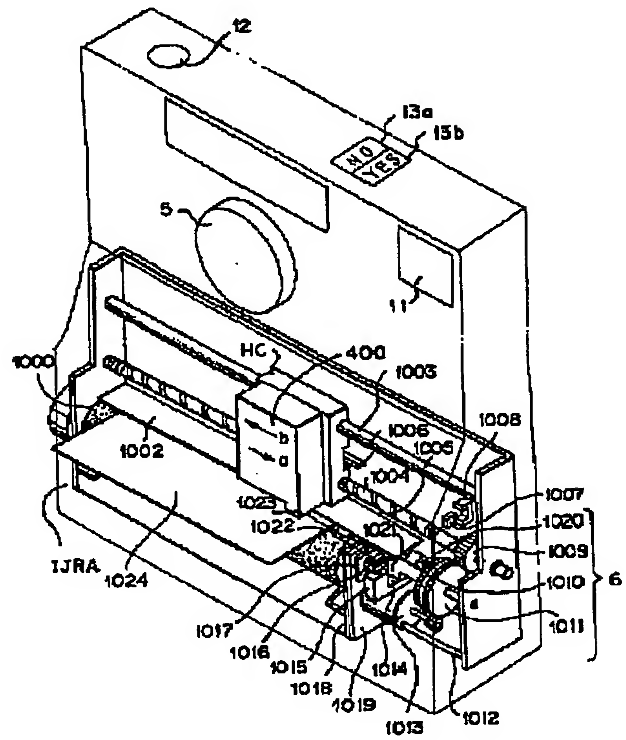
APPLICATION DATE : 20-10-95
APPLICATION NUMBER : 07273000

APPLICANT : CANON INC;

INVENTOR : SUZUKI ETSURO;

INT.CL. : H04N 5/765 H04N 5/781 B41J 29/38 G03B 17/16 G03B 17/48 H04N 5/225 H04N 5/76 H04N 5/91

TITLE : IMAGE PICKUP DEVICE WITH PRINTER



ABSTRACT : PROBLEM TO BE SOLVED: To prevent the operation of the printer from being overlapped with the operation of charging of a main capacitor of a strobo light emitting section In a composite camera.

SOLUTION: The image pickup device with a printer where the image pickup device with a strobo light emitting section 11 recording video information onto a recording medium and the printer printing out the video information onto recording paper are integrally provided is provided with a control means controlling the operation of the strobo light emitting section 11 during the operation of the printer and the control means stops charging of the strobo light emitting section 11 onto a main capacitor during the printing operation of the printed. Furthermore, the control means stops the print operation till the charging to the main capacitor is finished when the print operation start button 13b to start printing is depressed while the main capacitor of the strobo light emitting section 11 of the image pickup device is being charged.

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04N 1/21 | A1

(11) International Publication Number: WO 95/16323

(43) International Publication Date: 15 June 1995 (15.06.95)

(21) International Application Number: PCT/US94/13803

(22) International Filing Date: 2 December 1994 (02.12.94)

(30) Priority Data:
9325076.9 7 December 1993 (07.12.93) GB

(71) Applicant (*for all designated States except US*): FISHER-PRICE, INC. [US/US]; 636 Girard Avenue, East Aurora, NY 14052 (US).

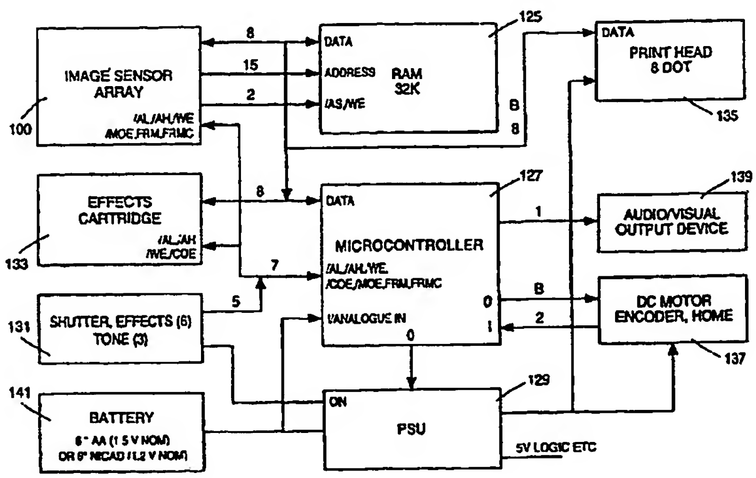
(72) Inventors; and
(75) Inventors/Applicants (*for US only*): THOMPSON-BELL, Ian [GB/GB]; 7 Cock Hall Close, Litlington, Herts SG8 0RB (GB). CANE, Michael, Rodger [GB/GB]; 10 George Street, Cambridge CB4 1AJ (GB). BEADMAN, Michael, Andrew [GB/GB]; 2 Cheyney Street, Steeple Morden, Royston, Herts SG8 0LP (GB). CIGANKO, David, J. [US/US]; 4546 Winding Woods, Hamburg, NY 14075 (US). LOVE, Stephen, John [GB/GB]; Rugby House, 39 Hilton Street, Over, Cambridgeshire CB4 5PU (GB). PRIESTMAN, Paul, Diminic [GB/GB]; 19 Penbridge Mews, London W11 3EQ (GB).

(74) Agents: GRIFFIN, William, J. et al.; Howrey & Simon, 1299 Pennsylvania Avenue, N.W., Washington, DC 20004-2402 (US).

(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SI, SK, TJ, TT, UA, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: INSTANT SPECIAL EFFECTS ELECTRONIC CAMERA



(57) Abstract

An instant special effects camera is disclosed which provides children in the age range of five years and up with an opportunity to take photos and see the results instantly. Fun special effects may be added to the pictures and the cost per picture is less than that of conventional film cameras. The camera is a battery operated electronic black and white camera with an integral direct thermal printer. A replaceable paper cassette is included. To improve ease of use and reduce cost, a minimal number of simple controls are provided. A picture may be taken simply by aiming the camera through a double view finder and pressing the shutter button. No setting up or flash is required. Plug-in special effects cartridges may be provided to increase the number of special effects.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	GB	United Kingdom	MR	Mauritania
AU	Australia	GE	Georgia	MW	Malawi
BB	Barbados	GN	Guinea	NE	Niger
BE	Belgium	GR	Greece	NL	Netherlands
BF	Burkina Faso	HU	Hungary	NO	Norway
BG	Bulgaria	IE	Ireland	NZ	New Zealand
BJ	Benin	IT	Italy	PL	Poland
BR	Brazil	JP	Japan	PT	Portugal
BY	Belarus	KE	Kenya	RO	Romania
CA	Canada	KG	Kyrgystan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo			SE	Sweden
CH	Switzerland	KR	Republic of Korea	SI	Slovenia
CI	Côte d'Ivoire	KZ	Kazakhstan	SK	Slovakia
CM	Cameroon	LI	Liechtenstein	SN	Senegal
CN	China	LK	Sri Lanka	TD	Chad
CS	Czechoslovakia	LU	Luxembourg	TG	Togo
CZ	Czech Republic	LV	Latvia	TJ	Tajikistan
DE	Germany	MC	Monaco	TT	Trinidad and Tobago
DK	Denmark	MD	Republic of Moldova	UA	Ukraine
ES	Spain	MG	Madagascar	US	United States of America
FI	Finland	ML	Mali	UZ	Uzbekistan
FR	France	MN	Mongolia	VN	Viet Nam
GA	Gabon				

Mimosa V2-05-00 10:16:24

INSTANT SPECIAL EFFECTS ELECTRONIC CAMERA

BACKGROUND OF THE INVENTION

The present invention relates generally to a hand-held electronic imaging camera and, more particularly, to an electronic camera capable of recording an image of a scene and thereafter electronically manipulating the image and producing a hard copy print on a paper sheet. The electronic camera is designed to be operated by a child, and captures the image with a charge coupled device (CCD). The hard copy printout is preferably produced with a thermal printer.

Electronic imaging cameras capable of recording an image of a scene and providing a hard copy printout using a thermal printer are known in the art. For example, U.S. Patent No. 4,074,324 to Barrett discloses an instant electronic camera which focuses an image on a CCD having a planar array of photosensors. Signals from the CCD are digitized and placed in a shift register memory. The contents of the shift register memory are then output to a dot matrix printer having heat-sensitive paper. Other electronic cameras with printer devices are shown, for example, in U.S. Patent No. 4,262,301 to Erlichman, published European Patent Application No. 574,581 to King Jim Co., published PCT Application No. WO 92/11731 to Eastman Kodak Co., and published European Application No. 398,295 to Minolta Camera.

In a typical electronic camera of this type, the camera optical system focuses an image on a conventional CCD chip having an array of photosensors. The photosensors produce analog signals proportional to the intensity of incident light. These analog signals are digitized by an analog-to-digital converter and stored in a random access memory. The capture, conversion and storage of the image is normally controlled by a microprocessor. The microprocessor can then control the print head of an associated printer mechanism to provide a hard copy of the captured image. Optional software for the microprocessor can process the image stored in the random access memory to enhance the quality of the printed image or to produce special effects such as an outline image.

Electronic cameras of this type have several disadvantages. Because the CCD array operates at a relatively high speed, and the printer typically operates at a relatively low speed, it is often necessary to store the entire captured image in the random access memory. A typical conventional CCD array can capture 80,000 or more picture elements (pixels), each of which is

stored in memory. This requires a relatively large memory which adds to the cost of the camera. The system described in PCT Application No. WO 92/11731 attempts to overcome this disadvantage by coupling the CCD array directly to a printer. However, this system introduces additional disadvantages and limits the available options.

For many applications, it is not necessary to capture 80,000 or more pixels to produce a satisfactory image quality. For example, for a child's electronic camera, a CCD device with a 160 x 160 array of photosensors (25,600 pixels) or a 190 x 160 array of photosensors (30,400 pixels) may provide sufficient picture resolution. Using a lower resolution CCD array can save costs for both the CCD chip and the random access memory.

To produce a satisfactory printed image quality, it is necessary to produce the appearance of shades of gray in the hard copy print out. However, a thermal printer is only capable of producing black or white dots. As a result, the microprocessor must manipulate the data in the random access memory to produce the appearance of shades of gray in the printout. Algorithms for producing this effect, known as dithering techniques, are known in the art. A typical dithering technique would operate on a block of pixels one line wide and two or three lines high. Thus, to create the first line of the printed image, the microprocessor needs to operate on only the first two or three lines of the captured image. Therefore, if a system could be arranged so that only two or three lines of data had to be stored in the random access memory at a given time, the size of the random access memory could be reduced by a factor of ten or more, with a consequent savings in cost.

Because the CCD array produces analog outputs at a relatively high rate, it is usually necessary for both the digital-to-analog converter and the random access memory to operate at high speed. Cost would be reduced if the CCD array could be arranged to capture an image at high speed, but output the image at relatively low speed, therefore allowing a slower analog-to-digital converter and random access memory to be used.

It is a primary objective of the present invention to overcome the described disadvantages of the prior art as well as other prior shortcomings, and to provide a relatively low cost electronic camera for children which is capable of providing plain prints as well as prints with special effects features.

BRIEF SUMMARY OF THE INVENTION

The present invention provides a low cost instant special effects camera suitable for use by children, and provides an affordable alternative to film cameras. In the preferred embodiment, an image sensor includes an array of photosensors which provide analog image outputs proportional to the intensity of light incident on the respective photosensors. The image sensor preferably includes timing logic for controlling operation of the photosensor array, as well as an analog to digital converter for digitizing the analog image outputs and interface logic. Electronic exposure control may also be provided to allow the use of low cost fixed aperture camera optics.

A memory stores the digitized image data from the image sensor for later processing by a microcontroller. To allow the use of a low pin count, low cost microcontroller, the microcontroller accesses data in the memory through the image sensor interface and a multiplexed address/data bus. In operation, the microcontroller retrieves data from the memory and applies contrast enhancement, magnification, dithering and data compression algorithms to prepare the data for printing. The print-formatted data is then stored back in the memory.

The microcontroller applies selected special effects to the print-formatted data as it is retrieved from memory for printing. Information for a plurality of standard special effects, including processing algorithms and/or data, may be provided in ROM internal to the microcontroller. Additional special effects information may be provided by optional ROM packs which may be inserted in the camera. A manual switch may be provided on the camera housing to permit a user to select specific special effects. Additionally, random selection of the special effects information may be chosen.

An integral printer is provided in the camera body, and paper may be supplied by replaceable paper cassettes. Audible and/or visual indications maybe provided to alert the user to the status of the camera processing.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects, advantages and features of the present invention will become apparent to the skilled artisan from the following detailed description, when read in light of the accompanying drawings, in which:

Fig. 1 is a schematic block diagram of a typical prior art electronic camera with a hard copy output;

Fig. 2 is a block diagram of a conventional CCD imaging array;

Fig. 3 is a block diagram of a custom CCD imaging array for use in an electronic camera;

Fig. 4 is a block diagram of one embodiment of an improved electronic imaging camera using a custom CCD array;

Fig. 5 is a block diagram of a preferred custom imaging sensor;

Fig. 6 is a block diagram of a preferred embodiment of an electronic imaging camera using the imaging sensor of Fig. 5;

Fig. 7 is a flow chart illustrating the operation of the electronic imaging camera of Fig. 6;

Fig. 8 illustrates a pulse width modulation technique for controlling printing operation;

Fig. 9 is a flow chart illustrating an exposure control scheme for use with the electronic imaging camera of Fig. 6;

Fig. 10 is a front view of a camera housing for the electronic imaging camera of Fig. 6;

Fig. 11 is a rear view of the camera housing of Fig. 9;

Fig. 12 is a side view of the camera housing of Fig. 9; and

Fig. 13 is a bottom view of the camera housing of Fig. 9.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Fig. 1, a typical electronic camera utilizes a conventional CCD array 1 to capture an image focused on the CCD array by camera optics. The analog output of the CCD array 1 is digitized by an A/D converter 2 and stored in random access memory 3. A microprocessor 4 controls a print head 5 and printer mechanism 6 to provide a hard copy of the captured image. The microprocessor 4 may optionally include software to process the image stored in the random access memory 3 to enhance the quality of the hard copy image or to produce special effects such as an outline image.

As illustrated in Fig. 2, a conventional CCD array includes a plurality of photosensors 7 arranged in a matrix of rows and columns. Each photosensor represents a single pixel in the image. A vertical shift register 8 is associated with each column of photosensors. During operation, the analog image data from the photosensors 7 is gated into the vertical shift registers 8 by the CCD control 10. At this point, each vertical shift register contains one column of analog image information. Subsequently, the CCD control 10 shifts the data in the vertical shift registers 8, by one pixel in an upward direction. As a result, the topmost pixel of each column is shifted into the horizontal shift register 9 so that the horizontal shift register 9 then contains one row of image data. The contents of the horizontal shift register are then shifted to the right by one pixel at a time to the analog output terminal 11 by the CCD control 10. in this way, a row of image data is clocked out of the CCD array one pixel at a time. The horizontal shift register 9 is then filled with the next line of data by shifting the data in all the vertical shift registers 8 up one pixel. This line of pixel data is again output through the analog output terminal 11 by successive shifting of the horizontal shift register 9. This process is repeated until all lines of pixel data have been output from the analog output terminal 11.

Referring now to Fig. 3, the custom CCD array consists of a conventional CCD array 12 having, for example, a 160 x 160 pixel matrix, an analog to digital (A/D) converter 13, a tri-state buffer 14, control logic 15 and memory control logic 16. The busy signal 22, the transfer signal 21, the read signal 20 and the shutter signal 19 are used to control the operation of the device and are normally connected to an external microprocessor. The digital data signals 23, the address signals 17 and read/write signals 18 are used to transfer data to an external random access memory.

In operation, when the shutter signal 19 is asserted, the control logic 15 controls the CCD array 12 to capture a single image focused on the array by the camera optics. A filter may be provided to select light frequencies to which the photosensors are sensitive. During this process, the control logic 15 asserts the busy signal 22 to inform the external microprocessor that it is busy. When the image has been captured, the busy signal 22 is not asserted. When the transfer signal 21 is asserted, the control logic 15 transfers a predetermined number of lines of data from the CCD array 12 via the A/D converter 13 and tri-state buffer 14 to an external random access memory. The control logic 15 also controls the address in the external random access

memory at which each pixel is stored by controlling the memory control logic 16 which generates the address signals 17 and the read/write signal 18 which are also connected to the external random access memory. The control logic 15 asserts the busy signal 22 during the transfer. This process may be repeated until all the data from the CCD array 12 has been transferred.

Between each transfer of a predetermined number of lines, or once all the data has been transferred to the external random access memory, the data in the external random access memory can be read by asserting the read signal 20. When the read signal 20 is asserted, the control logic 15 and the memory control logic 16 control the address signals 17 and the read/write signal 18 to access a memory location in the external random access memory. While the read signal 20 is asserted, the tri-state buffer 14 is disabled to prevent the output of the A/D converter 13 from interfacing with the data read from the external random access memory. The address from which data is read is determined by the increment signal 24 and clear signal 25. When the clear signal 25 is asserted, the address is set to zero. Each time the increment signal 24 is asserted the address is incremented by one. In this way, an external microprocessor or other control circuit can access any of the data in the external random access memory.

Turning to Fig. 4, an improved electronic imaging camera includes a custom CCD array 26, such as that illustrated in Fig. 3, external random access memory 27, a microprocessor 28, a print head 29, a printer drive mechanism 30 and an optional plug-in module 31 which may comprise random access memory only, or a combination of random access memory and read-only memory.

In operation, the microprocessor 28 commands the custom CCD array 26 to capture an image when the shutter switch is operated. Once the image has been captured the custom CCD array 26 informs the microprocessor 28 that this operation is complete. When no plug-in module 31 provided, the microprocessor 28 then commands the custom CCD array 26 to transfer a predetermined number of lines of image data into the random access memory 27. The number of lines to transfer is determined by the functions the electronic imaging camera is expected to be able to perform without the benefit of the plug-in module 31. The amount of random access memory 27 is chosen to be just sufficient to hold the predetermined number of image data lines. In one embodiment, eight lines of data are transferred to the random access memory 27. Where one line of image data consists of 160 pixels, the 8

lines of image data requires 8 times 160 bytes, or 1,280 bytes. A low cost 2 kilobyte random access memory 27 can therefore be used. Transferring the image 8 lines at a time allows a simple dithering algorithm to be employed which will allow an acceptable but not high quality gray-scale hard copy to be produced. As each group of 8 lines of image data is transferred, the microprocessor 28 in cooperation with custom CCD array 26 accesses the image data one byte at a time, carries out the dithering algorithm, if required, then controls the print head 29 and the printer drive mechanism 30 to produce a hard copy image. Lines are transferred eight at a time to random access memory 27, manipulated and printed by the microprocessor 28, in cooperation with the print head 29 and printer drive mechanism 30 until the entire captured image has been printed.

In another embodiment, 4 kilobytes of random access memory 27 is provided and lines of image data are transferred in a block of 16 lines or two blocks of 8 lines to the random access memory 27. This allows the microprocessor 28 to employ a more sophisticated dithering algorithm which produces a correspondingly higher quality hard copy image.

To allow additional features and functions to be provided a plug-in module 31 may be connected to the electronic imaging camera. In one embodiment, the plug-in module 31 contains 32 kilobytes of random access memory. This allows the entire image to be transferred from the custom CCD array 26 to the plug-in module 31 before the image is printed. This allows more complicated effects to be produced which require the microprocessor to be able to access the entire image or large portions of the image. In addition, because the entire image is stored, extra copies of the image can be printed. Each copy can be identical to the previous one or modified, if required by pressing one of the effects switches 32. The effects that can be selected include, but are not limited to, binary image, outline image, contrast enhancement and the addition of a "speech bubble" such as are used in newspaper cartoons.

In another embodiment, the plug-in module contains read only memory, the contents of which represent a number of pre-stored images. These pre-stored images could include picture frames, places of interest, film or pop stars, animals or other images of an educational or entertainment nature. A particular image can be selected either by the operation of a switch incorporated in the plug-in module 31 or by the effects switches 32. The

image could be printed directly or used as a background over which a captured image could be superimposed.

Turning now to Fig. 5, a block diagram of the preferred custom image sensor is illustrated. Preferably, the image sensor array is constructed in accordance with PCT Published Application No. WO 91/04633 to VLSI Vision Ltd. ("VVL"). A test circuit for such an image sensor array is disclosed in PCT Published Application No. 91/04498. This type of imaging array is available from VVL as part of a monochrome monolithic camera under the trade name ASIS-1070. Customization of the array is available to suit a particular application.

Briefly, unlike the CCD array of Fig. 2, the VVL image sensor array does not utilize vertical shift registers to clock the data to an output port. Rather, a relatively compact array of pixels is provided with a series of horizontal word lines and vertical bit lines. Each pixel in a row is connected to a common horizontal word line which, in turn, is connected to driver control circuitry such as a shift register. Each vertical column of pixels is connected to a vertical bit line which is coupled to one input of an associated switch sense amplifier. A second input of the switch sense amplifiers is coupled to a switching control circuit. The output terminals of the switch sense amplifiers are connected to a common read-out line. In operation, the signals from the photosensors are effectively sequentially multiplexed onto the read out line through the switch sense amplifiers under direction of the driver control circuitry and the switching control circuit. For a more detailed description of such an image sensor array and its operation, reference may be had to the published VVL patent applications.

Fig. 5 illustrates a modified version of the VVL ASIS-1070 which forms an image sensor 100. The sensor 100 includes an image array similar to the ASIS-1070 image array, together with all the timing logic to control the array. In addition to the imaging array, the sensor 100 includes an analog to digital converter and all the logic necessary to interface with static RAM and a microcontroller. The design of the image sensor array is intended to allow the use of a low pin count, low cost microcontroller to process the image data and control the printer. The sensor array interface supports a minimum pin count interface between a system microcontroller and the system peripherals by combining the address and data bus and decoding the high and low address locally to the peripherals. The image is stored in static RAM and is accessed

using a multiplexed address/data bus to provide an interface with the microcontroller.

An array 101 of photosensors having an array size, for example, of 160 X 190 pixels, is provided with associated control circuits and switch sense amplifiers. In operation, row shift register 103 and column shift register 105 sequentially switch the data from the individual pixels through a bank of integrating amplifiers 107 to an output terminal 109. An eight bit analog to digital converter 111 digitizes the pixel data into eight bit data, and places the data in parallel on a data bus D_0-D_7 through a bi-directional data latch 112. A fifteen bit presettable binary counter 113 is provided to generate address signals for the individual data words on address bus A_0-A_7, A_8-A_{14}. A RAM interface is provided for write enable (WE) and address strobe (AS) signals which control transfers between the image sensor array and the system memory. The interface between the image sensor array and the RAM is a simple read/write interface using the address strobe line to latch the current address and the write enable line to control the read or write mode. Since the speed of the microcontroller interface will be relatively slow in comparison to the rate at which data becomes available on the multiplexed address/data bus during a read operation, this simple interface permits the use of a low cost RAM.

A mode controller 117 is included to allow the image sensor array to operate in a selected one of several available operating modes, as discussed more fully below. Automatic exposure control logic and timer control circuit 121 are provided to control the sensor exposure time and to synchronize system operation. The use of electronic exposure control circuit 119, which operates over a relatively wide range, permits the camera to use a low cost fixed aperture lens.

Turning now to Fig. 6, the image sensor array is arranged in a system including a static RAM 125, a microcontroller 127, and a power supply unit 129. The microcontroller 127 can be, for example, a commercially available Zilog Z86C76 microcontroller. The system also includes a plurality of switches 131 for controlling the shutter as well as the special effects and tone settings. An optional effects cartridge 133 in the form of an insertable memory package may also be provided. An eight dot print head 135 is provided for printing hard copies of images on thermal paper. Alternatively, an ink-jet or other appropriate type of printer may be used. Movement of the print head and paper transport are controlled by a DC motor encoder 137. An

audio/video output device 139 allows a user to monitor system operation through audible tones and/or a visible display such as an LCD screen or indicator lights. Additionally, a low cost electronic view finder could be provided which may be driven from either the microcontroller or the memory. The system may be powered by a battery 141, which may take the form, for example, of 6 AA cells (1.5V nominal) or 6 NiCad rechargeable cells (1.2V nominal).

In operation, the raw image is stored in the static RAM 125 by the image sensor array 100. The image may then be accessed using a multiplexed 8 bit address/data bus to provide the interface of the RAM 125 to the microcontroller 127 via the image sensor array 100. This interface allows the system to use a low pin count, low cost microcontroller such as the Zilog Z86C76. The microcontroller 127 processes the raw image data and converts it from the original 8 bit gray scale 190 x 160 resolution to a 2 bit gray scale 380 x 320 resolution image suitable for printing. The converted image is stored in the static RAM 125, and may be retrieved and combined with overlays and effects stored either internally within the microcontroller or externally in an optional effects cartridge 133. The effects cartridge 133 is preferably accessed using the same multiplexed address/data bus used for communications with the image sensor array 100 and the static RAM 125.

The microcontroller interface with the print subsystem includes a buffered 8 bit interface to the print head 135, and the DC motor control, optical encoder feedback and home sensor feedback 137. The thermal print head 135 is preferably a passive print head including eight dots each of approximately 35 ohms. The print head is controlled using an eight bit data latch to connect print data to the print head and to provide sufficient drive capability to place an NPN transistor into saturation to thereby turn on the individual print dots. The single transistor drive provides a benefit by reducing voltage requirements, in relation to Darlington pair transistors, to ensure maximum voltage across the print head. The print head interface writes to the latch by writing the required pattern to the address/data bus and driving the clock line of the latch high. If individual bits of the print head are required to be turned off earlier than others, then the latch can be rewritten with a new value at any time. At the completion of the print strobe time, all bits will be written to zero.

The DC motor interface is linked to the encoder feedback to provide speed control of the DC motor using a pulse width modulated (PWM)

system. During the printing cycle, the microcontroller will control the speed of the print head by reference to rotary encoder pulses fed back from an IR phototransistor which senses the position of the print head. These pulses are used to pulse width modulate the DC motor to maintain a constant speed at the print head, and to synchronize the print head strobe with the print head position to ensure good print registration. In addition to the encoder feedback, a home position sensor will provide a feedback to allow a mechanical registration at the start of each print line.

The DC motor will be turned on at the maximum pulse width (controlled by an internal timer interrupt) until the time between the encoder pulses is within a set range. If the time between encoder pulses becomes too short, then the motor will be slowed by increasing the amount of OFF time in the pulse code modulation. Conversely, if the time is too long, then the motor speed will be increased by increasing the ON time of the modulation signals. The encoder feedback may be used to synchronize the print strobe to the motor position, with an absolute line to line registration being provided by the home sensor input.

The effects cartridge 133 interfaces with the microcontroller 127 through the same multiplexed address/data bus lines through which the image sensor array 100 and the microcontroller 127 interface. A separate effects cartridge enable line is provided to enable the cartridge interface. This allows the system to distinguish between accesses to the RAM 125 through image sensor 100 and accesses to the effects cartridge ROM pack. Internally, the effects cartridge 133 preferably includes two eight bit latches for address data and plurality of ROM memory locations. To access a particular byte stored within the ROM pack, the microcontroller writes the low address byte on the multiplexed address/data bus, followed by the high address byte, and will then read back the data. If consecutive bytes are required, then the minimum operation will be to rewrite the low address bytes and read back the data. In the preferred embodiment, the high and low address bytes allow up to a 16 bit addressing range within the cartridge. Thus, the cartridge may store up to 64 kilobytes of data for use by the microcontroller.

The microcontroller 127 interfaces with the user through a series of switches 131, including the shutter button, a repeat picture button, and the effects cartridge selector input. The shutter button is connected to both the power supply and the microcontroller so that when the system is powered down, pressing the shutter button will power the system and take a picture.

If the system is already turned on, pressing the shutter will simply take another picture. The repeat picture button will operate only if pressed within a certain time period after the last picture was taken, for example, 2 minutes. Pressing the repeat picture button within that time period causes the system to reprint the picture with the current effects setting. The effects selection will consist of three binary coded inputs selected by a rotary selector. (See Figs. 10 and 12).

During operation, the system will produce an audible sound generated from a sound effects device. Preferably, the sound may be produced with a simple single transistor amplifier with a moving coil loudspeaker incorporated in the audio/visual output device 139. It may also be possible to utilize different sound effects to indicate different points in the camera cycle. For example, one sound effect may be used to indicate the picture has been taken or that the camera is taking a picture, and a second sound effect may be used while the camera is processing the image and printing it out. As an alternative to the sound effects, or in addition to the sound effects, visual indicators such as LED lights or an LCD display may be used to indicate the camera operation.

The microcontroller interface allows control of the image sensor 100 and the static RAM 125 using a number of operation modes. These modes include image control modes and memory control modes. As noted above, the image sensor 100 mode is controlled by the microcontroller through instructions to the address/mode decode logic 117. The imager control modes allow the interface to instruct the image sensor 100 to capture a frame of image data and place the frame in static RAM 125, and to set the exposure value in exposure control 119 following processing of the picture.

The memory control modes allow the microcontroller 127 to access the external RAM 125 via the image sensor using the multiplexed address/data bus. In the simplest form, the read and write mode operates by the microcontroller writing the low address byte followed by the high address byte, and reading back data or write data. The additional memory control modes increase the system efficiency by avoiding the microcontroller rewriting the address bytes. For instance, an RMW mode allows the microcontroller to perform a normal read operation followed by a write operation to the same address. Auto read or write cycles allow the microcontroller 127 to read or write consecutive bytes of the RAM 125 while the binary counter 113 of image sensor 100 automatically increments the

address. Thus, blocks of data may be read or written with only the first address being set. Such an arrangement is nearly as efficient as directly accessing the memory 125.

The basic software functions of the electronic camera are illustrated in flow chart form in Fig. 7. Prior to operating the camera, a user should set the three position tone control switch to the desired setting. In normal indoor use, the tone control should be set to medium. For operation in cold conditions such as outdoor winter use, the tone control should be set to dark; and in very hot weather, the light tone control setting should be used. As shown in Fig. 7, camera operation may be initiated by pressing the shutter button to power up the camera. The overall principle of the system is to capture the image as quickly as possible, apply all the standard enhancements and compression to the image, and store the print-formatted image back in the RAM 125 while printing an appropriate picture heading. Finally, the image is rotated as it is removed from the static RAM 125 and printed with the appropriate overlays, scaling, etc. being applied at that time. Finally, a picture footer such as a company logo may be printed. One benefit of the system is an ability to maintain the printable image in RAM 125 such that if another copy of the image is provided within the time-out period, the copies can be produced with alternative effects. A time-out period of approximately two minutes may be used to help conserve battery life.

Once the shutter button is pressed, an electronic exposure control is performed. The exposure control adjusts the pixel exposure time to compensate for reflected light from the main subject of the exposure, and allows the camera to use a low cost fixed aperture lens. The function of the electronic exposure control is discussed more fully in conjunction with Fig. 9.

The objective of the image processing software is to convert the 8 bit gray scale 160 X 190 image captured by the image sensor 100 into a 2 bit gray scale image at 320 X 380 resolution, with additional image enhancement to tailor the image for the print subsystem. The image processing consists of several main stages: contrast enhancement of the original data to increase the printed image contrast; magnification of the original image to 320 X 380 resolution for the printer; dithering and thresholding of the magnified image to reduce each pixel from 8 bit gray scale resolution to 2 bit gray scale resolution; and compression of the image to 4 pixels per byte to allow the image to be stored within the same 30,400 byte image areas as the original 8 bit image.

Since the hardware interface with the external RAM 125 is optimized to allow access to consecutive bytes of stored data, the image processing software preferably utilizes as much internal microcontroller RAM as is available to load pieces of the image, process them, and store them back into the external RAM 125. Assuming, for example, that 160 bytes of internal RAM are available in the microcontroller 127, a block of 40 bytes of original image data may be retrieved from the external RAM 125 for processing. Following magnification, the 40 byte block of image data fills an 80 byte by 2 row block of data, for a total of 160 bytes. After dithering, thresholding and data compression, each 40 bytes of original data becomes two rows of compressed data of 20 bytes each.

Contrast enhancement is applied to the original 40 bytes of image data as they are copied from the external RAM 125 to the microcontroller internal RAM. The contrast enhancement modifies the raw image data by applying a predetermined conversion function to map the raw image data into enhanced contrast data. Magnification increases the image size by converting each pixel of information into four pixels. In other words, the image data for a single pixel in the 160 x 190 original image is assigned to 2 x 2 array of pixels in the 320 x 380 resolution array. The dither algorithm reduces the 8 bit, 256 gray level original image data to 2 bit, 4 gray level data. Preferably, the dither algorithm is based on a Floyd Steinberg Dither algorithm which produces a black and white output. To achieve the reduction in gray scale values, the 8 bit gray scale values X of the image data are compared against the thresholds shown in the following table, and the 2 bit gray scale value is set accordingly.

Original 8 Bit Gray Scale Value	Resulting 2 Bit Gray Scale Value
$0 < X \leq 42$	0
$42 < X \leq 127$	1
$127 < X \leq 212$	2
$212 < X \leq 255$	3

The resulting 2 bit data is packed into four pixels per byte and stored in the external static RAM 125. To avoid discrepancies in the dither calculation of image data in adjacent blocks of image data, the image data bytes at the right of each processed block are maintained in 8 bit format and

are stored separately for use with the adjacent blocks when they are subsequently processed.

The printer control software drives a single DC motor to scan the print head and advance the paper. Synchronized with the print head position, the printer control software controls the data on the print head and the strobe time for the print head. The printer control software runs in parallel with the image processing software so that a header may be printed during image processing. Thus, the printer software is preferably operated under interrupt control.

The DC motor control is preferably a pulse width modulated (PWM) type control system with the feedback performed using a single rotary encoder system. The PWM output is produced with an internal timer set over a range of values dependent on the speed error. The speed error is calculated by the time taken between each encoder pulse. The basic printer control system is shown schematically in Fig. 8.

Print head control is performed by synchronizing the absolute print head position, using the rotary encoder, with the print data. As the print head moves, the encoder is used to synchronize the data being sent to the print head such that every line printed is registered to the previous line. To maintain the registration, the home sensor input is used to provide an absolute print head position feedback at the start of each line.

The print head ON time is controlled using a series of gray scale tables and an offset provided by the tone control position. The start of the ON time for all print dots is synchronized to the encoder feedback. The duration of the ON time for each pixel of the current line is chosen with reference to the required gray level for the pixel and 50% weighting for the gray level of the previous pixel. This ON time is offset with a fixed value determined by the tone control switch position to compensate for ambient temperatures.

As noted previously, special effects are applied to the print-formatted image stored in external RAM 125 as the image is retrieved for printing. A number of special effects are stored in microcontroller ROM and are available with the standard camera. For example, typical effects might include a "dollar bill" overlay to permit a user to print a friend's face on play money; an aquarium overlay; a speech bubble overlay; and a picture frame overlay. Additional effects may be provided by a ROM module in the optional plug-in effects cartridge 133. For example, image scaling factors may be included in a special effect to produce a "fun house mirror" image. To determine the

presence of the plug-in effects cartridge 133, a two byte signature is included in the cartridge to be read back at power up. If a cartridge is present, the cartridge effects will be used. Otherwise, the system will default to internal effects.

Each effect will include one or more of the following parts: overlays which are compressed using run length compression; contrast modifiers to modify the contrast algorithm; exposure modifiers to change the average exposure value for long exposure type effects; x-axis image scaling factors for an entire image to produce a stretched or compressed image; x,y coordinate image offsets to allow the entire picture to be offset within an overlay; line scaling factors to be applied line by line; and line offsets for each image line to be used with the line scaling factors. Other possible features which could be provided through the effects cartridge include: a self timer to allow a user to take a self portrait or the like; electronic zoom which expands the center of the captured image to fill the entire picture area; a mirror effect provided by printing only half of the captured image and then repeating this image in reverse; and fading by a complex overlay so that the edge of the picture fades to white. It should be noted that contrast and exposure modifiers will affect the original image and thus will not be adjustable when using the repeat picture functions.

The effect to be applied, if any, is preferably selected by the user through a rotary switch on the camera housing. The position of the rotary switch sets three binary coded inputs which are read by the microcontroller 127. Such a rotary switch is shown in Figs. 10 and 12. Preferably, a random setting may also be provided whereby the microcontroller randomly selects one of the available special effects for printing.

Turning now to Fig. 9, the exposure control is performed as soon as the shutter button is pressed. The electronic exposure control algorithm performs a first pass using a random line within the captured image. This allows the software to calculate an approximate exposure value without waiting for the entire frame to be captured. This exposure value can then be written directly into the exposure register in exposure control 119 of the image sensor 100 and another frame started. If the random line of the new frame is within the required exposure range, the center of the frame will be used to calculate a more accurate exposure value. If necessary, another frame will be requested to improve the image. When the exposure is within tolerance, the captured image will be further processed and printed.

The exposure calculation may be performed by calculating an average 8 bit gray scale level of all the pixels in the area under consideration. The exposure register contents will be modified from the error between the calculated average gray scale level and the midpoint 8 bit value 128. As a first approximation, the exposure register contents will be set to a center value on power up, and will be modified up or down from that value for a more accurate exposure at the particular light level.

For improved results, the exposure setting may be center weighted within the picture frame such that the exposure will be calculated with respect to the object at the center of the frame. This technique provides several advantages. First, it helps ensure that the exposure is correct for the main subject of the image. Also, calculation of the exposure value will only require a limited number of pixels to be considered and therefore will be much faster. Additionally, the effect of back-lighting/front-lighting will be minimized as only the main subject of the picture will be considered by the algorithm.

The housing for the camera is illustrated in Figures 10-13. Referring to the frontal view of Fig. 9, the housing includes a top molding 200 and a bottom molding 202 which may be formed of an appropriate plastic material. A knurled lens ring/effects switch 204 is provided for selecting a special effect from the optional special effects ROM pack 206 or, if no special effects pack is included, from the standard special effects stores in the ROM of the system microcontroller. Rotation of the lens ring 204 sets three binary coded inputs to be decoded by the microcontroller 127. Preferably, a visual indication such as a pointer arrow is provided on the lens ring to indicate the current effects setting.

The upper molding 200 preferably includes a clear plastic cover 208 for the printer paper output. The upper molding 200 and the lower molding 202 are each provided with peripheral gripping portions. A shutter button 210 is arranged on a gripping portion of the upper molding. Additionally, a picture repeat button (not shown) may be provided on the upper molding 200. The top portion of the upper molding 200 receives a view finder molding 212, which provides viewing apertures 214 and 216. The viewing apertures 214 and 216 are preferably covered with clear eye piece moldings 214A and 216A, respectively.

A rear view of the camera housing is illustrated in Fig. 11. The view finder molding 212 includes a pair of eye pieces 214B and 216B associated

with viewing apertures 214 and 216, respectively. A connector 218 is provided for attaching a carrying strap (not shown). The rear portion of the special effects ROM pack 206 includes a recessed gripping portion 206A to facilitate removal from the camera body.

Referring to the side view of Fig. 12, the lower molding 202 includes a paper cassette cover 220. Thermal printing paper may be provided in a replaceable cassette which is received in an aperture of the system printer mechanism. A typical paper cassette would include sufficient paper to supply approximately 50 hard copy prints. As shown in the bottom view of Fig. 13, the lower molding 202 includes a battery cover 222 in addition to the paper cassette cover.

The principles, preferred embodiments and modes of operation of the present invention have been described in the foregoing specification. The invention which is sought to be protected herein, however, is not to be considered as limited to the particular forms disclosed, since these are to be regarded as illustrative rather than restrictive. Variations and changes may be made by those skilled in the art without departing from the spirit of the invention.

WHAT IS CLAIMED IS:

1. An electronic camera for providing instant hard copy pictures, comprising:

an image sensor including a plurality of photosensors arranged in an array for providing analog image data outputs proportional to the intensity of light incident on the respective photosensors, said image sensor further including additional processing circuitry;

an analog to digital converter for digitizing the analog image data outputs of said photosensor array;

a memory for storing the digitized image data from said image sensor;

a microcontroller coupled with said image sensor, said microcontroller operable to retrieve said digitized image data from said memory by way of said image sensor and to prepare said digitized image data for printing; and

a printer operating under control of said microcontroller to provide a hard copy picture.

2. The apparatus of claim 1, wherein said analog to digital converter is provided as part of said image sensor.

3. The apparatus of any one of claims 1 and 2, wherein said microcontroller processes said image data in accordance with special effects information.

4. The apparatus of claim 3, wherein said special effects information is provided in read-only memory internal to said microcontroller.

5. The apparatus of claim 4, further including a replaceable special effects cartridge having read-only memory for storing said special effects information.

6. The apparatus of any one of claims 1-5, wherein the additional processing circuitry of said image sensor includes timing logic for controlling the photosensor array and interface logic.

7. The apparatus of any one of claims 1-6, wherein said microcontroller is coupled with said image sensor by a multiplexed address/data bus, and wherein said digitized image data is retrieved by the microcontroller from said memory by way of said multiplexed address/data bus.

8. The apparatus of any one of claims 5-7, wherein said special effects cartridge communicates with said microcontroller over said multiplexed address/data bus.

9. The apparatus of any one of claims 3-8 wherein information for a plurality of special effects is available and said microcontroller selects information for one of said plurality of special effects.

10. The apparatus of claim 9, further including a manual switch which may be set by a user to control the special effects information selected by said microcontroller.

11. The apparatus of any one of claims 9 and 10, wherein said microcontroller selects special effects information at random.

12. The apparatus of any one of claims 1-11, further including a tone control switch whereby a user can adjust the tone of the printed output in accordance with the camera operating environment.

13. The apparatus of any one of claims 1-12, wherein said printer includes a thermal print head.

14. The apparatus of any one of claims 1-13, wherein said image sensor includes an electronic exposure control circuit and wherein the electronic camera includes an exposure control algorithm for setting the exposure time of said exposure control circuit.

15. The apparatus of claim 14, wherein said exposure control algorithm weights a portion of the image in determining a desired exposure time.

16. A special effects camera for providing and instant hard copy picture, comprising

a plurality of photosensors arranged in an array for providing analog image data signals proportional to the intensity of light incident on the respective photosensors;

an analog to digital converter for digitizing the analog image data signals from said photosensor array;

means for processing said digitized image data signals to prepare said data for printing;

a replaceable special effects unit including information for a plurality of special effects, said processing means operable to process said image data signals in accordance with selected information for one of said special effects; and

a printer operating under control of said processing means to provide a hard copy special effects picture.

17. The apparatus of claim 16, wherein said processing means selects the special effects information at random.

18. The apparatus of any one of claims 16 and 17, further including a manually actuable mode selection switch which permits a user to control the selection of the special effects information.

19. The apparatus of any one of claims 16-18, further including a memory for temporarily storing said digitized image data signals prior to processing by said processing means, said processing means operable to format said digitized image data signals for printing and to store the formatted data back in said memory, said processing means further operable to retrieve said formatted data from said memory and to apply the special effects information to said formatted data prior to printing.

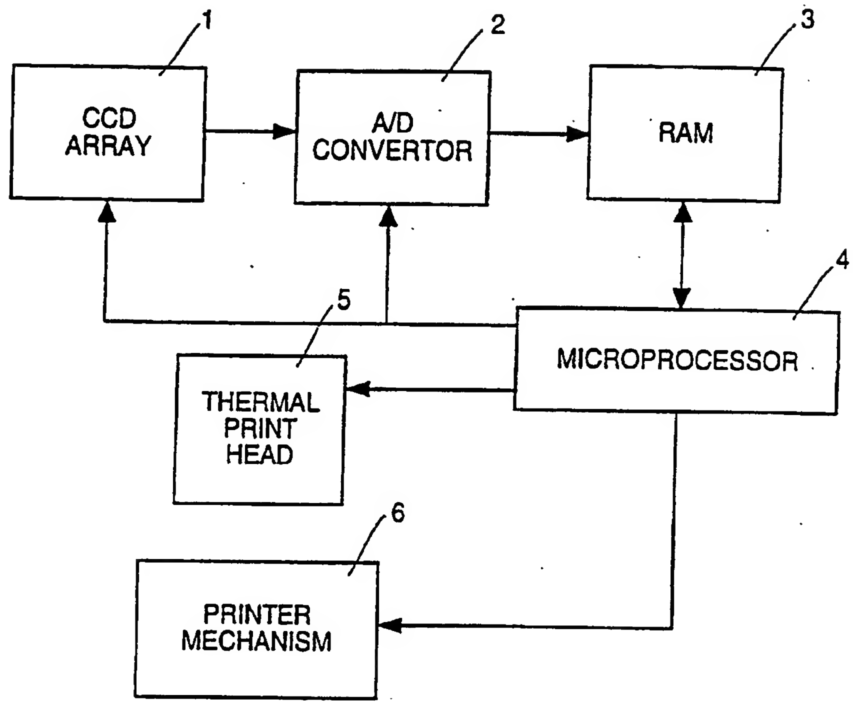

CCD ARRAY
1
A/D CONVERTOR
2
RAM
3
MICROPROCESSOR
4
THERMAL PRINT HEAD
5
PRINTER MECHANISM
6

FIG. 1

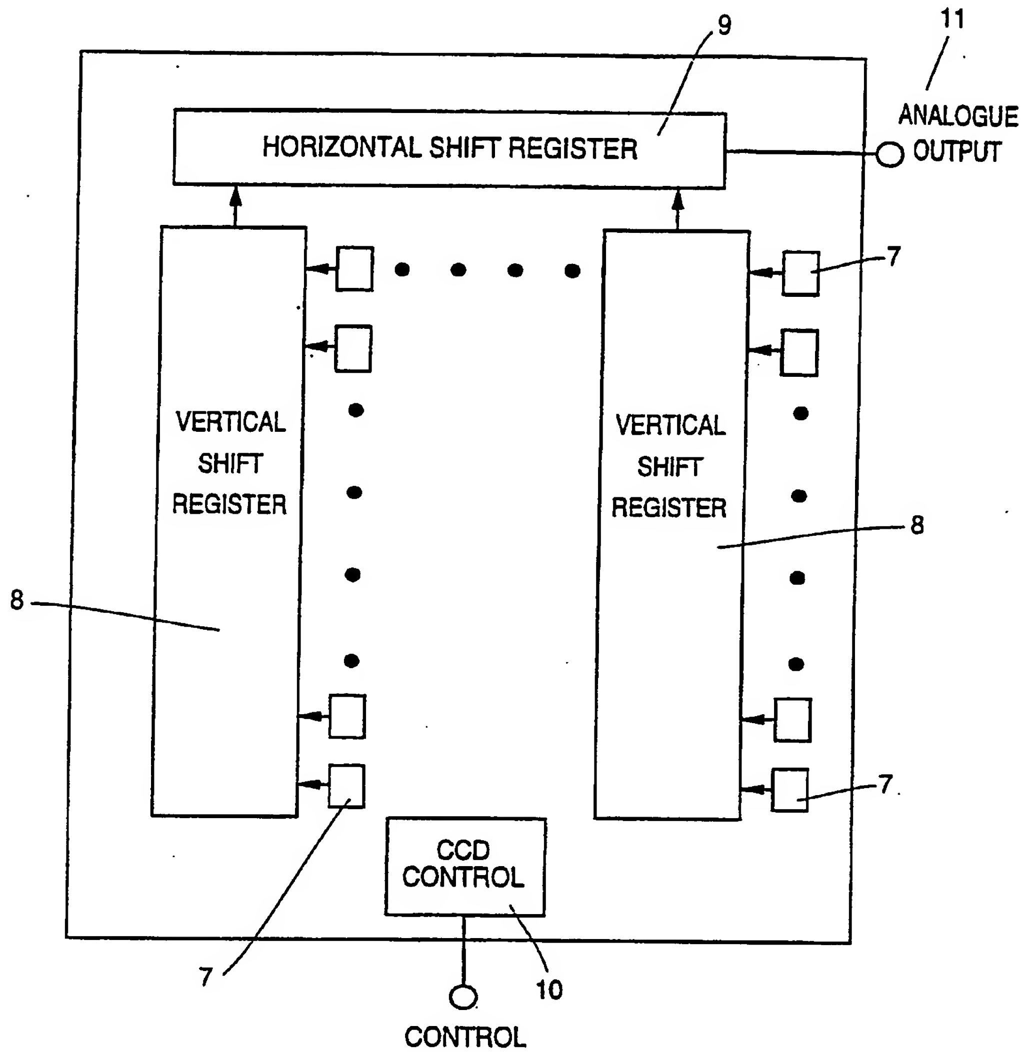

9
11
ANALOGUE OUTPUT
HORIZONTAL SHIFT REGISTER
7
VERTICAL SHIFT REGISTER
VERTICAL SHIFT REGISTER
8
8
7
7
CCD CONTROL
10
CONTROL

FIG. 2

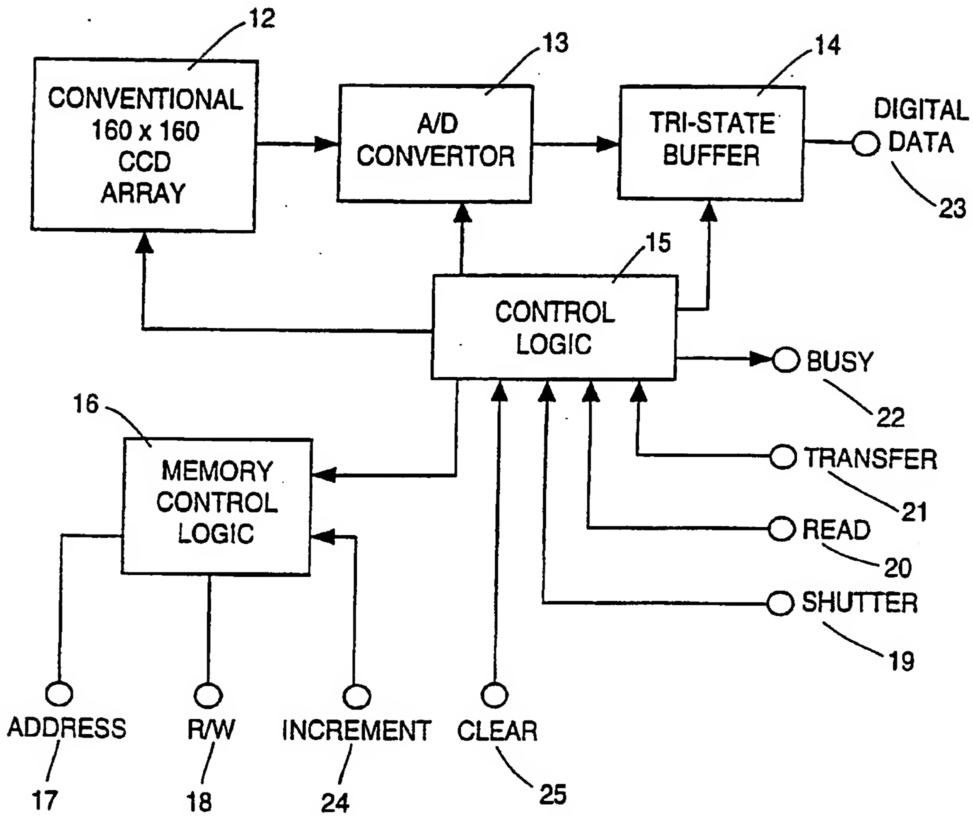

12
CONVENTIONAL 160 x 160 CCD ARRAY
13
A/D CONVERTOR
14
TRI-STATE BUFFER
DIGITAL DATA
23
15
CONTROL LOGIC
BUSY
22
TRANSFER
21
READ
20
SHUTTER
19
16
MEMORY CONTROL LOGIC
ADDRESS
17
R/W
18
INCREMENT
24
CLEAR
25

FIG. 3

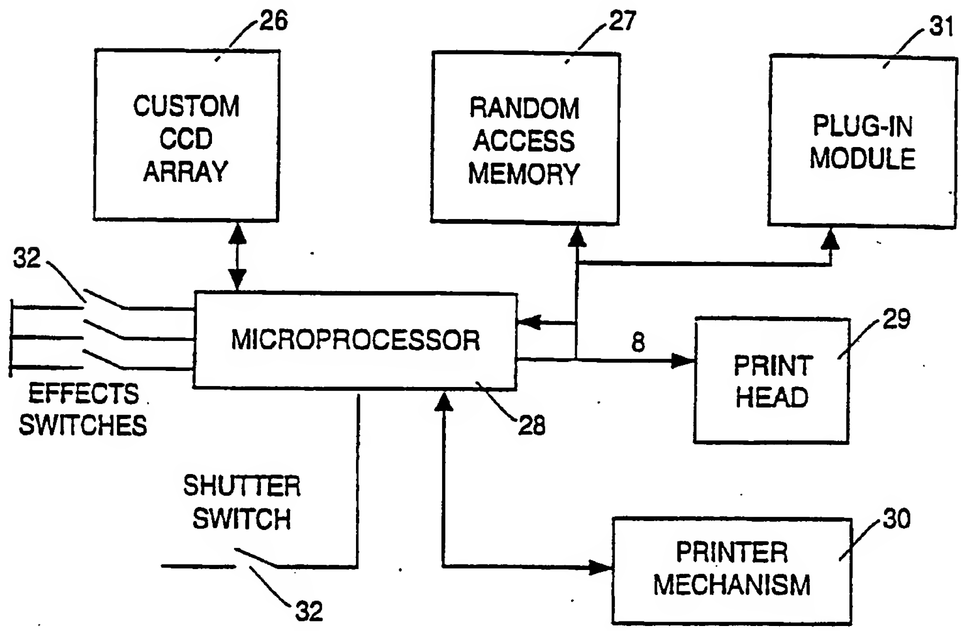

26
CUSTOM CCD ARRAY
27
RANDOM ACCESS MEMORY
31
PLUG-IN MODULE
32
MICROPROCESSOR
8
29
PRINT HEAD
EFFECTS SWITCHES
28
SHUTTER SWITCH
30
PRINTER MECHANISM
32

FIG. 4

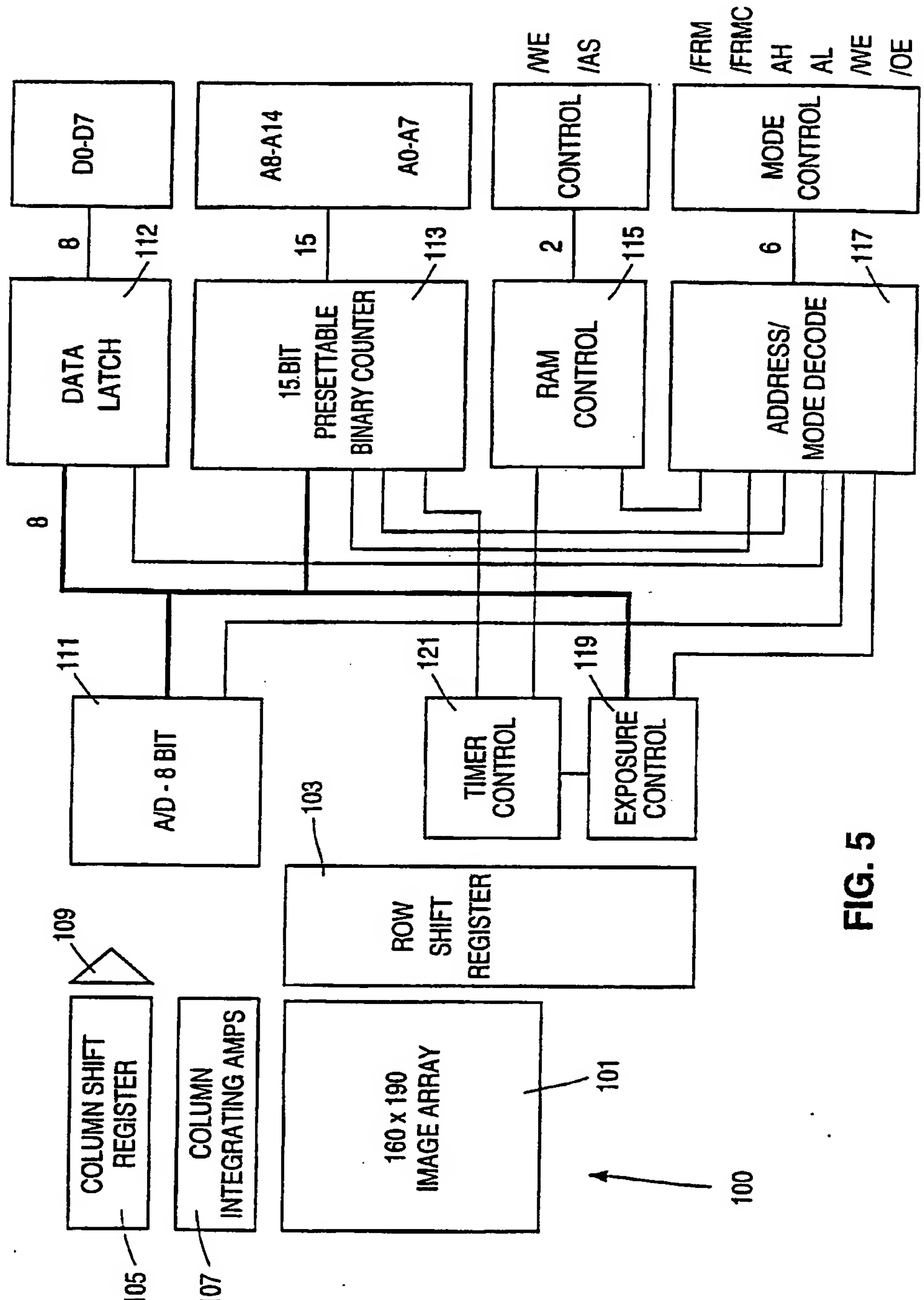

D0-D7
A8-A14
A0-A7
CONTROL
/WE
/AS
MODE CONTROL
/FRM
/FRMC
AH
AL
/WE
/OE
8
15
2
6
112
113
115
117
DATA LATCH
15.BIT PRESETTABLE BINARY COUNTER
RAM CONTROL
ADDRESS/ MODE DECODE
8
111
121
119
A/D - 8 BIT
TIMER CONTROL
EXPOSURE CONTROL
103
ROW SHIFT REGISTER
109
COLUMN SHIFT REGISTER
COLUMN INTEGRATING AMPS
160 x 190 IMAGE ARRAY
101
100
105
107

FIG. 5

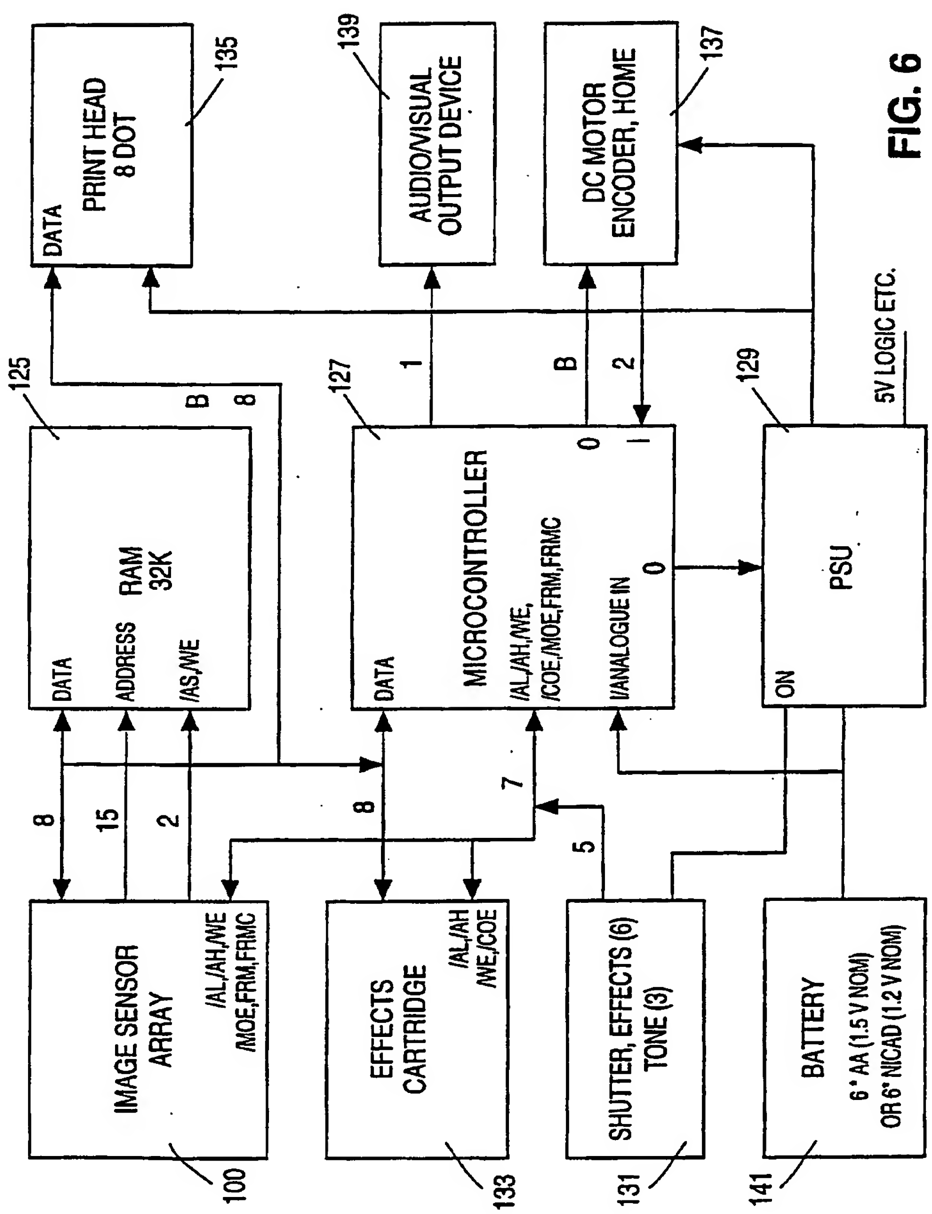

PRINT HEAD
8 DOT
DATA
135
AUDIO/VISUAL
OUTPUT DEVICE
139
DC MOTOR
ENCODER, HOME
137
RAM
32K
DATA
ADDRESS
/AS,/WE
125
B
8
MICROCONTROLLER
DATA
/AL,/AH,/WE,
/COE,/MOE,FRM,FRMC
I/ANALOGUE IN
127
1
B
2
0
I
0
PSU
ON
129
5V LOGIC ETC.
8
15
2
8
7
5
IMAGE SENSOR
ARRAY
/AL,/AH,/WE
/MOE,FRM,FRMC
100
EFFECTS
CARTRIDGE
/AL,/AH
/WE,/COE
133
SHUTTER, EFFECTS (6)
TONE (3)
131
BATTERY
6 * AA (1.5 V NOM)
OR 6* NICAD (1.2 V NOM)
141

FIG. 6

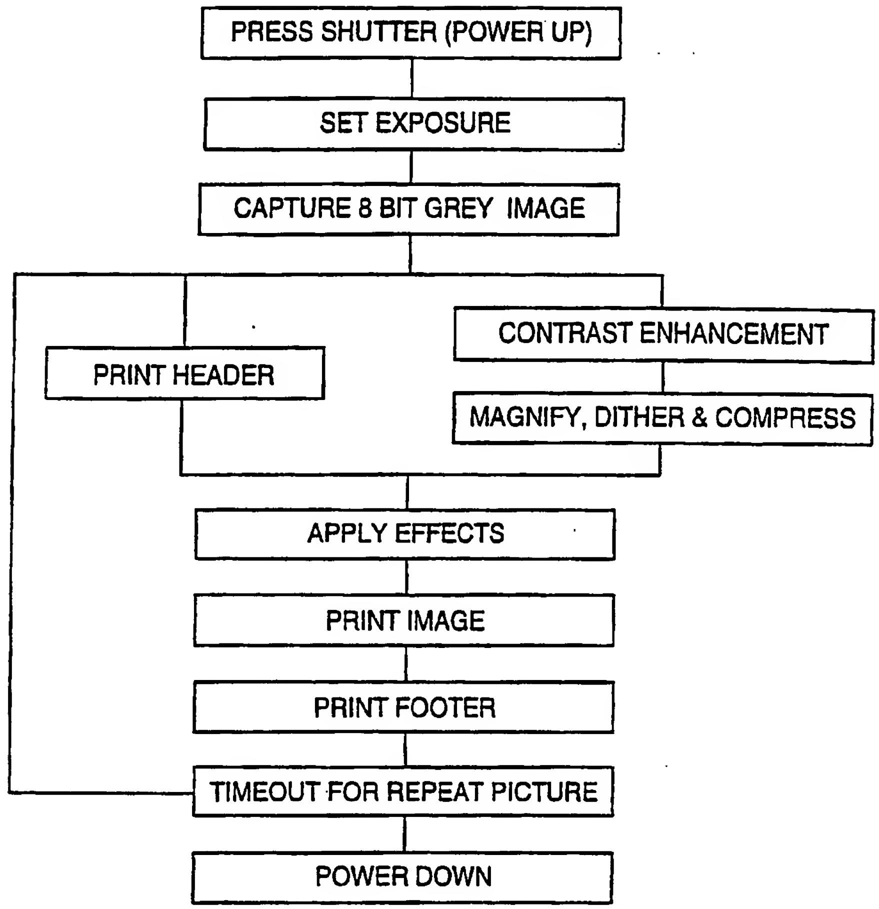

PRESS SHUTTER (POWER UP)
SET EXPOSURE
CAPTURE 8 BIT GREY IMAGE
PRINT HEADER
CONTRAST ENHANCEMENT
MAGNIFY, DITHER & COMPRESS
APPLY EFFECTS
PRINT IMAGE
PRINT FOOTER
TIMEOUT FOR REPEAT PICTURE
POWER DOWN

FIG. 7

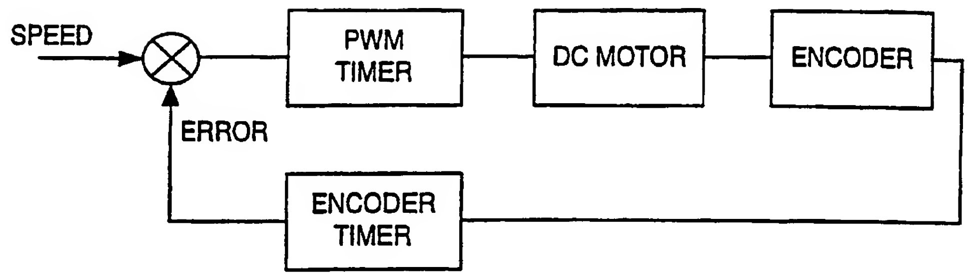

SPEED
PWM TIMER
DC MOTOR
ENCODER
ERROR
ENCODER TIMER

FIG. 8

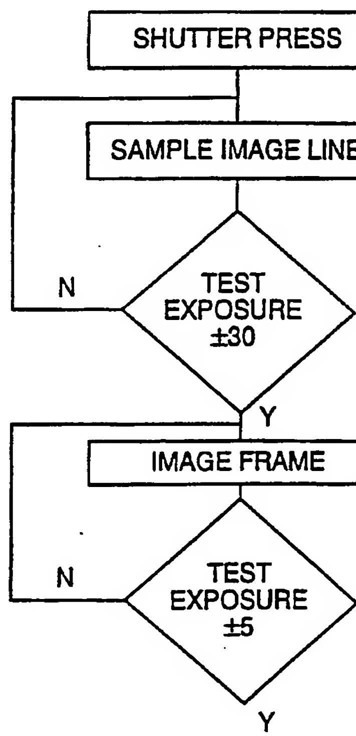

SHUTTER PRESS
SAMPLE IMAGE LINE
N
TEST EXPOSURE ±30
Y
IMAGE FRAME
N
TEST EXPOSURE ±5
Y

FIG. 9

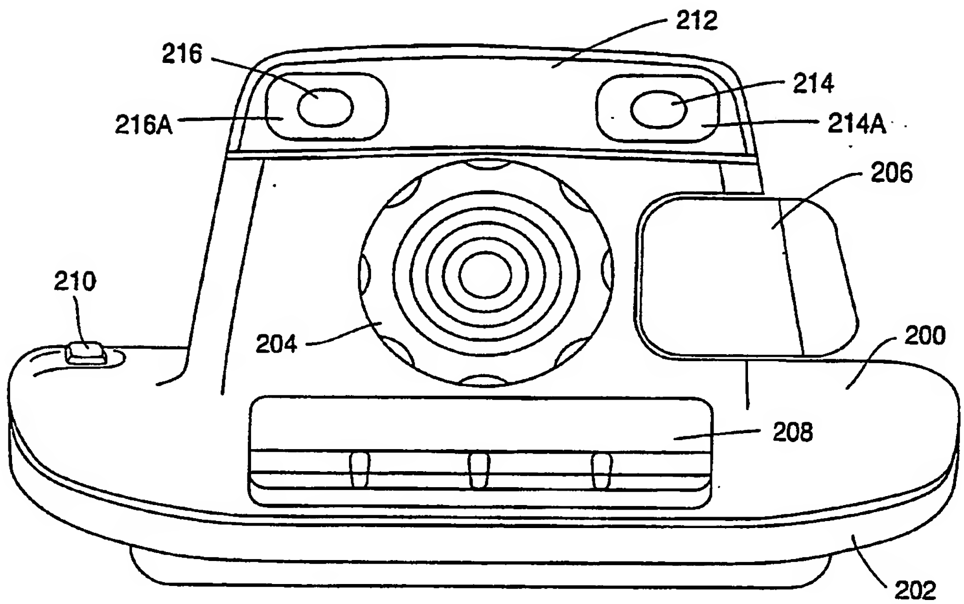


FIG. 10

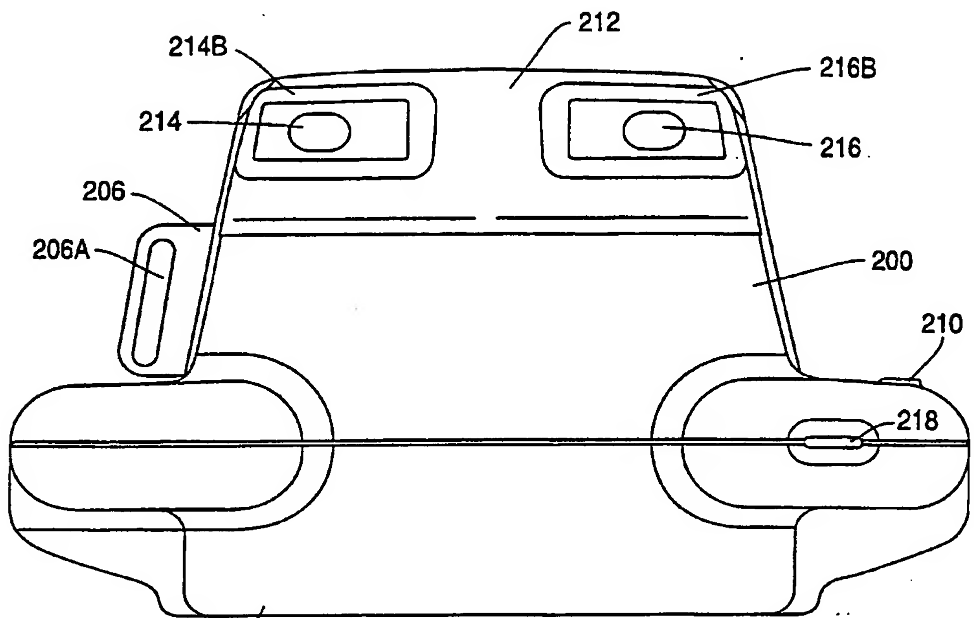

212
214B
216B
214
216
206
206A
200
210
218
202

FIG. 11

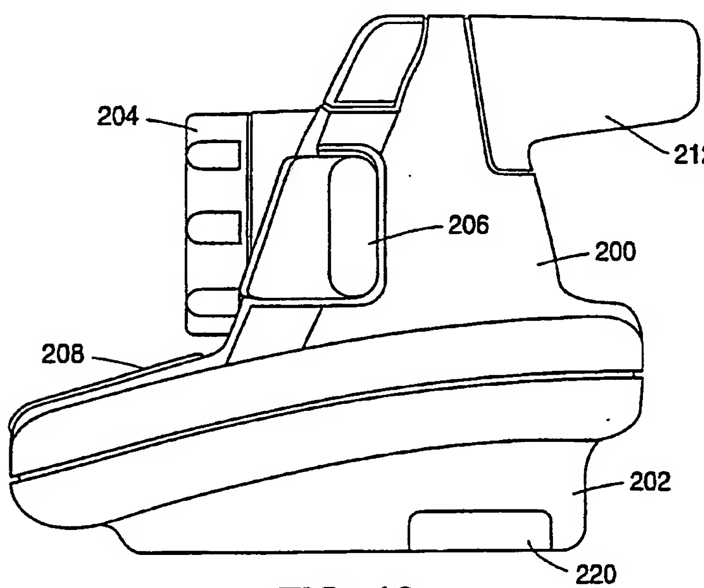

204
212
206
200
208
202
220

FIG. 12

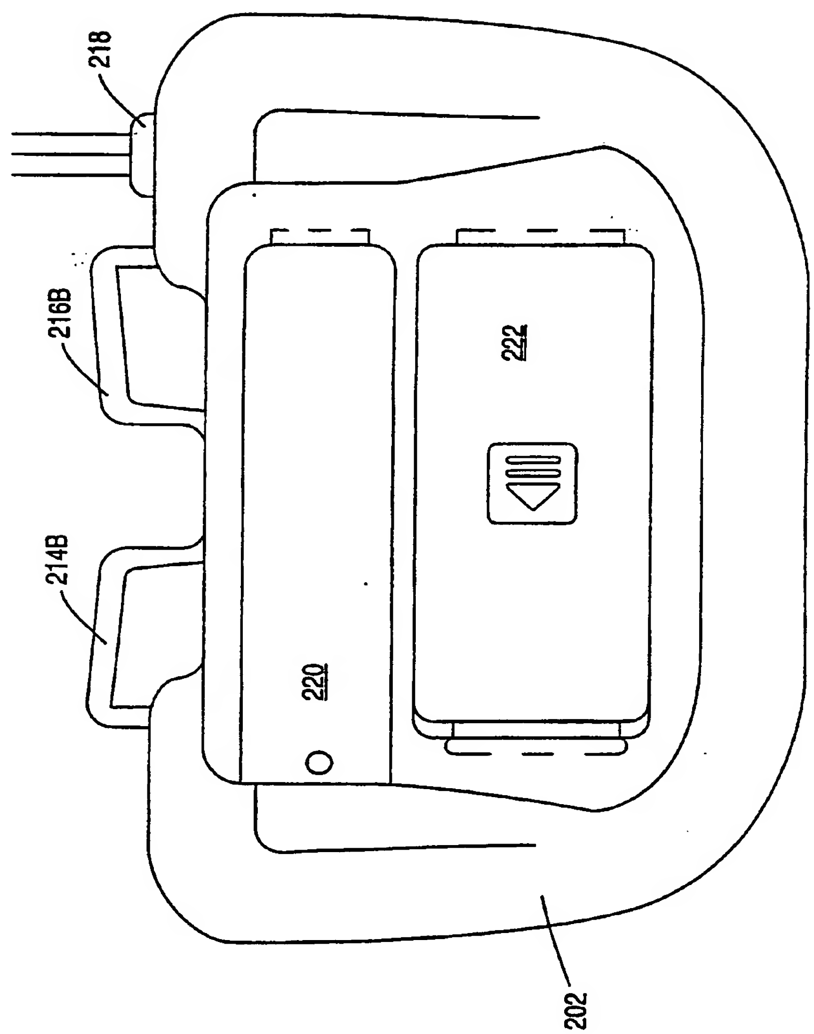


FIG. 13

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 94/13803

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04N1/21

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO,A,91 14336 (KING JIM CO., LTD.) 19 September 1991	1-4,6,9, 13,16,19
P,Y	& EP,A,0 574 581 (KING JIM CO., LTD.) 22 December 1993 see the whole document	1-4,6,9, 13,16,19
Y	IEEE INTERNATIONAL SYMPOSIUM ON CIRCUITS AND SYSTEMS, 3 May 1990, NEW ORLEANS pages 1705 - 1708, XP163546 K. CHEN ET AL 'PASIC: A PROCESSOR-A/D CONVERTER-SENSOR INTEGRATED CIRCUIT' see the whole document	1-4,6,9, 13
Y	US,A,4 577 229 (DE LA CIERVA, SR. ET AL.) 18 March 1986	16,19
A	see abstract	5

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
23 March 1995	25.04.95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Hazel, J

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB,A,2 263 841 (ASAHI KOGAKU KOGYO KABUSHIKI KAISHA) 4 August 1993 see abstract -----	10,18

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 94/13803

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
WO-A-9114336	19-09-91	JP-A-	3261276	21-11-91
		AU-A-	7440891	10-10-91
		EP-A-	0574581	22-12-93
EP-A-0574581	22-12-93	JP-A-	3261276	21-11-91
		AU-A-	7440891	10-10-91
		WO-A-	9114336	19-09-91
US-A-4577229	18-03-86	NONE		
GB-A-2263841	04-08-93	JP-A-	2097176	09-04-90
		JP-A-	2096733	09-04-90
		JP-A-	2097184	09-04-90
		JP-A-	2097177	09-04-90
		JP-A-	2097178	09-04-90
		DE-A-	3933155	05-04-90
		DE-A-	3943664	06-08-92
		DE-A-	3943665	09-07-92
		DE-A-	3943666	30-07-92
		DE-A-	3943667	06-08-92
		FR-A-	2637386	06-04-90
		FR-A-	2672176	31-07-92
		GB-A,B	2225687	06-06-90
		GB-A,B	2263838	04-08-93
		GB-A,B	2263839	04-08-93
		GB-A,B	2263840	04-08-93
		US-A-	5111299	05-05-92